OD-30393
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NAVSEA-OD-30393
FIRST REVISION

DESIGN PRINCIPLES AND PRACTICES FOR CONTROLLING HAZARDS OF ELECTROMAGNETIC RADIATION TO ORDNANCE (HERO DESIGN GUIDE)

THIS PUBLICATION SUPERSEDES NAVWEPS
OD 30393 DATED 15 JUNE 1965

PUBLISHED BY DIRECTION OF
COMMANDER, NAVAL SEA SYSTEMS COMMAND

DISCLAIMER NOTICE

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15 SEPTEMBER 1974

LIST OF EFFECTIVE PAGES

Total number of pages in this manual is 74 consisting of the following:

Page No.	# Change No.
Title - A	0
Foreword-Record of Changes	0
v - x	0
1 - 3	0
4 (Blank)	0
5 - 21	0
22 (Blank)	0
23 - 59	0
60 (Blank)	0
61 - 63	0
64 (Blank)	0

Zero in this column indicates an original page.

RECORD OF CHANGES

CHANGE NO.	DATE	TITLE OR BRIEF DESCRIPTION	ENTERED BY

FOREWORD

NAVSEA OD 30393 has been prepared as a guide for HERO preventive techniques to be applied to the design and construction of weapon systems and subsystems. The information contained herein should not be construed as a specification but as an aid in implementing the requirements of MIL-STD-1385 (Navy), Preclusion of Ordnance Hazards in Electromagnetic Fields, General Requirements For.

Comments for the improvement of this publication are invited. Recommended additions, corrections, or deletions should be addressed to the Commander, Naval Sea Systems Command; Attn: SEA-00B4; Washington, D. C. 20362. Additional copies may be obtained upon request from the Commanding Officer, Naval Ordnance Station, Louisville, Kentucky 40214, Attention Code CTDO.

TABLE OF CONTENTS

Page Number

LIST OF TABLES

LIST OF ILLUSTRATIONS

Chapter I.
INTRODUCTION

1.0 GENERAL

Modern communication and radar transmitters can produce high intensity electromagnetic environments that are hazardous to ordnance and to its attending personnel and associated equipment. These environments can cause premature actuation of sensitive electrically initiated explosive elements known as electroexplosive devices (EEDs). They can also damage or trigger solid state circuits, damage or cause erratic readings in test sets, cause possible biological injury to personnel, or produce sparks that can ignite flammable fuel-air mixtures. The trend of developing communication and radar transmitters with greater radiated power will increase these problems in the future.

This Design Guide is intended primarily to help the weapon developer solve the problem of premature actuation of EEDs; however, it should be of some help in solving all of the problems given above. The problem of premature actuation of EEDs is known as Hazards of Electromagnetic Radiation to Ordnance (HERO).

Energy from the electromagnetic environment can enter an ordnance item through discontinuities in its skin such as ports, cracks, and joints, and it can couple into circuits containing EEDs. More energy will generally enter the ordnance item when the ports are open than will enter it when the ports are closed. The energy can also be conducted into the item by firing leads and other electrical conductors such as wires, tools and fingers. In general, ordnance is more susceptible in electromagnetic environments during assembly, disassembly, handling, loading and unloading than at any other time because fingers and tools are used and ports are usually open. Also, the attachment of external cable assemblies and test sets to an ordnance item will usually increase its electromagnetic susceptibility.

For most ordnance, the HERO problem is inevitable unless the designer recognizes the possible hazard and organizes all phases of the development so that the hazard is precluded in the original design. Retrofitting after a HERO problem is discovered at some later stage of development is, at best, expensive and time consuming, and seldom contributes to the tactical reliability of the ordnance.

1.1 OBJECTIVES OF THE DESIGN GUIDE

This design guide has been written to amplify and augment MIL-STD-1385 (Navy), Preclusion of Ordnance Hazards in Electromagnetic Fields, General Requirements for. Its objectives are:

1. To define and describe the hazardous electromagnetic environment.
2. To provide weapon designers with sufficient engineering data for determining the protection needed for ordnance.
3. To recommend specific design and fabrication practices.

While it is recognized that each ordnance item will be unique with respect to HERO, an effort has been made to present recommended design practices and associated engineering data and theory in a manner that will assist the designer to adapt various recommendations to his particular situation.

1.2 POSSIBLE SOLUTIONS TO THE HERO PROBLEM

Resolution of the HERO problem might logically be approached in any one of four ways. They are:

1. Eliminate all EEDs from the ordnance.
2. Keep all ordnance containing EEDs physically separated from the electromagnetic environment.
3. Silence the transmitter generating the local electromagnetic environment when ordnance containing EEDs is present. *
4. Design the ordnance to prevent entry of electromagnetic energy into the EEDs.

These are all valid solutions. However, the first three have serious drawbacks which are as follows:

1. EEDs have unique characteristics and the elimination of EEDs is often not a practical solution.
2. It is usually impossible to keep the ordnance separated from the

* Some weapons now in the fleet require that radio or radar transmitters be silenced during certain phases of their assembly, disassembly, handling or loading. This constitutes a restriction to fleet operations. Current restrictions are published in a manual generally available only to the fleet. Restrictions are not desirable and are becoming less acceptable to the fleet as new and safe weapons are developed to replace the ones that have restrictions.

electromagnetic environment on-board Naval vessels.

3. It is not practical to silence the radio or radar transmitters.

Therefore, designing every weapon system in such a way that sufficient protection is afforded the EEDs under all conditions that may be encountered throughout the stockpile-to-launch sequence is the only satisfactory solution.

1.3 BASIC APPROACHES TO THE HERO PROBLEM

There are several approaches that can be considered for solving the HERO problem. These are discussed in the following paragraphs.

One approach consists of enclosing all EEDs and their associated firing circuits (including all power sources, transmission lines, and switching and arming devices) within a conductive shield or box. Most ordnance items utilize a metallic skin that can be used as a conductive box. This approach is illustrated in Figure 1-1. The only precautions to be observed is the proper design of the metallic joints. In most cases, economic or other limitations on the physical structure of the ordnance do not permit direct application of the conductive box concept.

The conductive box concept can be extended by having several parts of an ordnance item compartmentalized and shielded, and then interconnected via shielded cable. Any cable connector used to connect the shields to the compartments should be of proper design so that the shield mates before the pins to prevent electromagnetic energy from being coupled into the pins of the connector during mating and unmating of the connector. This approach is illustrated in Figure 1-2.

Most ordnance requires breaking electrical connections when the parts of the system are physically separated. Thus it is often impossible or impractical to keep all conductors within one continuous

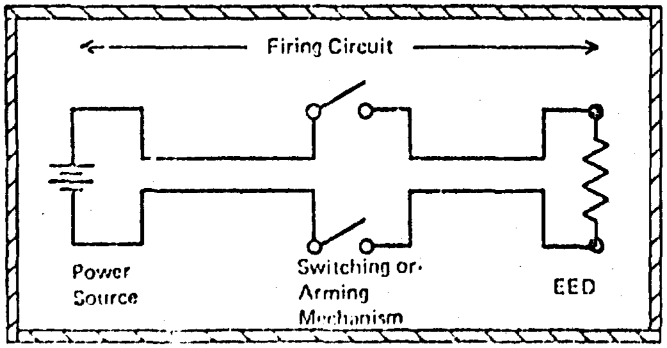


Figure 1-1. The Conductive Box Concept

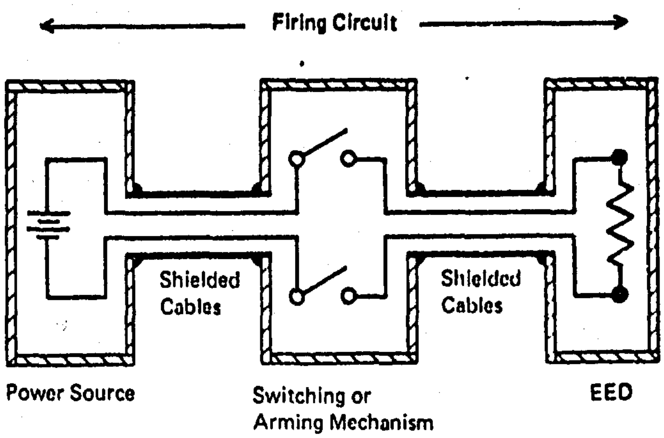


Figure 1-2. Compartmentalization, and Shielding of Compartments and Connections

shield. Therefore, electromagnetic energy must be excluded by some other method. It can be excluded from a shielded enclosure at a connector by means of an EMI filter (a low-pass filter). The filter is used to dissipate the electromagnetic energy instead of reflecting it at an impedance mismatch as is usually the case. Because the generator and the load impedances are unknown and vary with frequency, reflection due to mismatch of impedances cannot be relied on to protect the weapon. One precaution to be noted is that the heat generated in the filter by dissipation of the electromagnetic energy must be prevented from actuating the EED. This can be accomplished by providing a separation of the EED and the filter or by providing a heat sink. The proper use of a filter is illustrated in Figure 1-3. For further details refer to Chapter VI.

The design of the circuits associated with the use of an EMI filter is important. Arcs can occur when connectors are mated or unmated in electromagenetic environments. These arcs can generate electromagnetic energy throughout the spectrum, including low frequency components which are in the same band as the firing signal, and will pass through the filter. A break in the firing circuit between the arc and the EED until after the connection is made will circumvent this problem because a dc path is necessary for an arc to occur. This technique is illustrated in Figure 1-4.

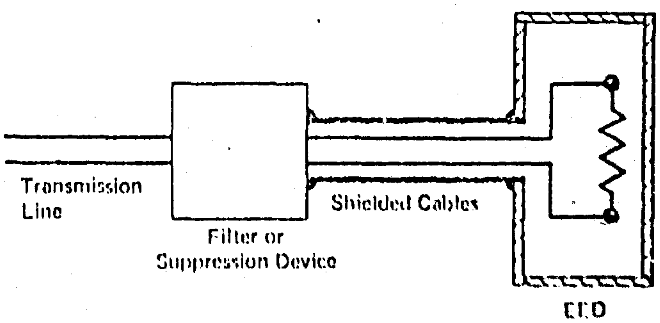


Figure 1-3. Use of EMI Filter

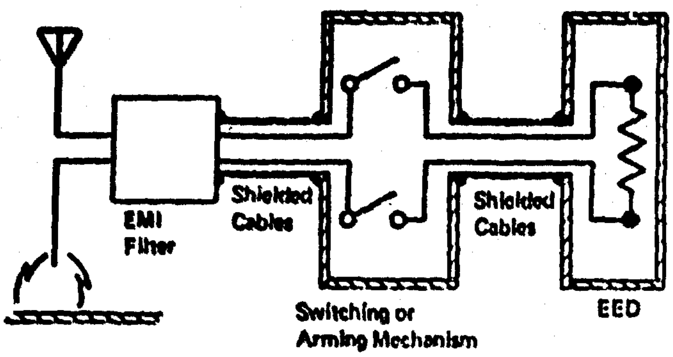


Figure 1-4. A Basic Solution to the Arcing Problem

To summarize, there are four basic approaches to the solution of the HERO problem:

1. Enclose the entire ordnance in a continuous electromagnetic shield.
2. Shield the compartments and the interconnecting cables of the firing circuits.
3. Use an EMI filter in the firing circuit and shield the cable from the filter to the EED.
4. Provide a break in the firing circuit between the filter and the EED for protection from arcs.

One of these approaches, or a suitable combination of them, must be selected early in the design stage and implemented throughout the design, development, and manufacture to assure an optimum and economical solution to the HERO problem. It is the responsibility of the weapon developer to select the approach to be used and to determine the attenuation values of the filters and the shielding effectiveness of the enclosure and the cables that will be needed. One way to solve this problem is to consider the ordnance as a receiving system in the electromagnetic environment and the EEDs as the terminating load for this receiver. The total attenuation needed can then be determined. A good rule of thumb is to provide additional protection so that the total attenuation from the combination of all shielding (that provided by weapon enclosure and cables plus that provided by the protection added) is 40 dB at 100 kilohertz and increases linearly to 60 dB at 1 megahertz. The attenuation should remain at or above 60 dB from 1 megahertz to 40 gigahertz.

Chapter II.

THE ELECTROMAGNETIC HAZARD

2.0 GENERAL

The electromagnetic susceptibility of ordnance is discussed in this chapter in terms of three major factors. These are: (1) identification and description of the electromagnetic environment to which the ordnance may be exposed, (2) possible modes of energy transfer from the environment to the EED, and (3) measurement of the environment. Although the information given herein is not essential to the implementation of the principles and guidelines to be established in later chapters, it is presented to give the weapons designer an insight into the need and purpose of these principles and guidelines and to present him with environmental levels to be used as design goals.

2.1 SUMMARY OF THE ELECTROMAGNETIC ENVIRONMENT

The available power in the electromagnetic environment at the weapon site is a function of the power radiated from the source, the source antenna gain, and the location of the ordnance relative to the source. The basic relationship of these factors can be derived by reference to an isotropic radiator. An isotropic radiator is a theoretical concept defined as a point source with radiation properties that are identical in all directions. For an isotropic radiator in free space radiating an average power (W_T) in watts, the power density or power per unit area on the surface of a sphere, concentric with the point source and of radius (r) meters, is the total radiated power divided by the area of that sphere, or

$$P_A = \frac{W_T}{4\pi r^2}$$

where

P_A = power density (watts/meter^2).

From this equation, it can be seen that power density in free space decreases inversely as the square of the distance from the radiating source.

If the power source is not an isotropic radiator but radiates with a gain in a given direction, the power density at a point of distance (r) meters in the direction of the gain is

$$P_A = \frac{G_T W_T}{4\pi r^2}$$

where

G_T = gain of the transmitting antenna (a unitless ratio).

In the far field the power density and the electric field strength at any point are related by

$$P_A = \frac{E^2}{120\pi}.$$

or

$$E = \sqrt{120\pi P_A} \simeq 19.4\sqrt{P_A},$$

where

E = electric field strength (volts/meter).

The factor 120π is known as the intrinsic impedance of free space and is approximately 377 ohms.

If the power density is in milliwatts/cm^2 and the electrical field strength is desired in volts per meter, the conversion factor of 1 watt/meter^2 = 0.1 milliwatts/cm^2 is used and the equation becomes

$$E = 61.4\sqrt{P_A}$$

where

E = volts/meter, and

P_A = Power density (milliwatts/cm^2).

The electric field from a transmitter in free space can be computed for any point if the distance to the point, gain of the antenna in the direction of the point, and the power being transmitted are known. Consider the field from a half-wave dipole in free space at a point of distance (r) meters from the antenna in the direction of maximum gain. From the equations

$$P_A = E^2/120\pi \text{ and } P_A = \frac{G_T W_T}{4\pi r^2},$$

we have

$$E = \frac{\sqrt{49.2 W_T}}{r} = \frac{7.01}{r}\sqrt{W_T}$$

where

G_T = 1.64 for a dipole.

The antenna gain is sometimes expressed in decibels (dB). From the definition of dB (dB = 10 log (ratio of two amounts of power)) we have

$$g_T = 10 \log G_T$$

or

$$G_T = 10^{g_T/10},$$

where

g_T = antenna gain in dB.

2.2 SUMMARY OF ENVIRONMENTAL LEVELS

The degree of electromagnetic susceptibility of existing ordnance, as determined by analysis of data obtained on HERO tests, is indicated by the maximum safe field curves presented in Figures 2-1 through 2-4. The curves shown by the heavy lines represent the upper limit of the field to which all types of ordnance in any condition can be exposed without HERO problems. These curves are the basis for present weapon restrictions in the fleet.

The maximum safe field curves in Figures 2-1 and 2-2 are based on theoretical and empirical consideration of the receiving characteristics of bare EEDs exposed in an electromagnetic environment. These curves represent the worst case condition which can exist for naval ordnance. The data will be useful in determining the maximum safe fields for bare EEDs with lead wires arranged in optimum receiving orientation. There has been no known case of an EED initiating accidentally when the field intensity was below the values given by the curves.

The maximum safe field curves of Figures 2-3 and 2-4 represent the safe field strength and power densities for fully assembled ordnance undergoing normal handling and loading operations. These curves are based on experimental results of HERO tests. The boundaries were established by the most susceptible ordnance items (those in which little or no design consideration was given to HERO problems).

Table 2-1 gives the maximum electromagnetic environment that ordnance will encounter from its stockpile-to-launch sequence. The trend in both radar and communications equipment toward greater effective radiated power will increase these fields. Past experience can yield some indication of the magnitude of the increase to be expected in the future. For example, early magnetron tubes could supply 10 kw of peak power to a matched antenna. Within a decade, the peak power of magnetron tubes increased to 1100 kw. Figure 2-5 shows the increase in average power that has been experienced over the last three decades and that which is expected to occur in the next two decades.

2.3 POWER LEVELS

In discussing the power levels of the environment, the effects of modulation on the power levels must be considered. Many communication systems use forms of amplitude modulation. If the transmitter is amplitude modulated the peak envelope power may be as high as 4 times the peak power of the unmodulated wave. However, this has been taken into account in determining the maximum environmental levels of Table 2-1.

Most radar systems use pulse modulation as opposed to the continuous carrier or doppler system. The important parameters of the pulsed system are: τ = pulse width (microseconds), f_r = pulse rate (hertz), P_p = peak power (kilowatts), and W_A = average power (kilowatts). There is a definite ratio between the peak and the average power that depends on the pulse width and the pulse rate. This relationship is called the duty ratio and is expressed as follows:

$$\text{Duty ratio} = \frac{\text{average power}}{\text{peak power}} = \frac{W_A}{P_p},$$

and

$$\text{Duty ratio} = \text{pulse width} \cdot \text{pulse rate} = \tau f_r.$$

(These parameters are shown in Figure 2-6.) Also, the average power can be computed from the duty ratio as

$$W_A = P_p \cdot \text{duty ratio} = P_p \tau f_r$$

or

$$W_A = P_p \frac{\tau}{T},$$

where

T = pulse repetition time = $1/f_r$.

2.4 ANTENNAS

Antennas may be conveniently grouped into two general classes according to the value of the ratio of the antenna's physical size to the wavelength of the transmitted frequency. When this ratio is much greater than unity, the antenna is classed as a large radiator; when it is in the order of unity, the antenna is classed as a small radiator. No consideration has been given here to antennas in which this ratio is much less than unity, because antennas of this type are inefficient radiators and are not usually found aboard ship.

One type of small radiator is the half-wave dipole. Some of the characteristics of this antenna are shown in Figure 2-7. Monopole and long wire antennas are considered variations of this type.

Large radiators that are used aboard ship are almost always radar antennas and are most frequently (where high power is concerned) employed with search, height, or guidance radars. Such antennas usually consist of dish-type reflectors. The reflector is designed to alter the phase and amplitude relationships of the feed antenna to focus the

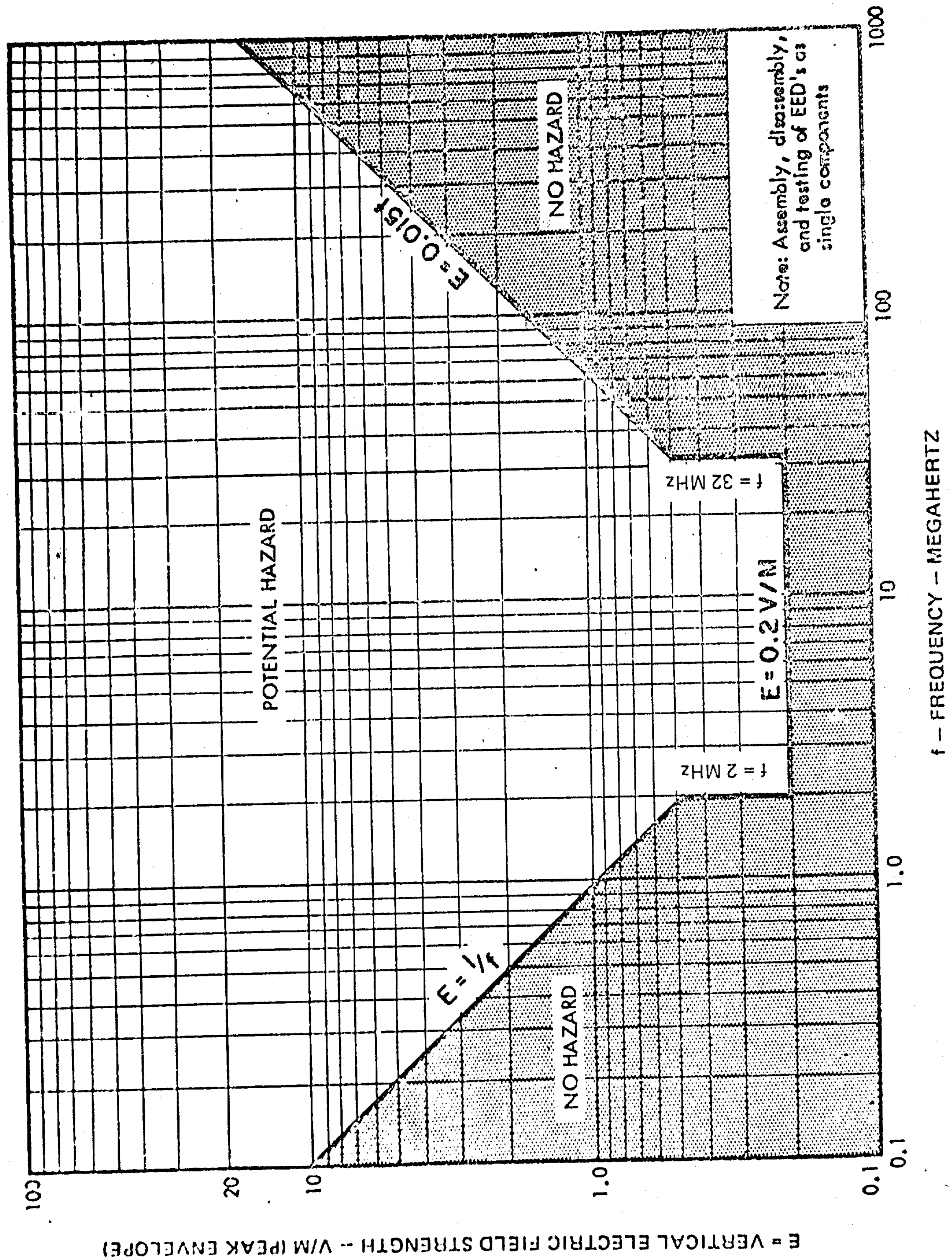


Figure 2-1. Field Intensity Potentially Hazardous to Ordnance in Optimum Coupling Configurations—Communication Frequencies

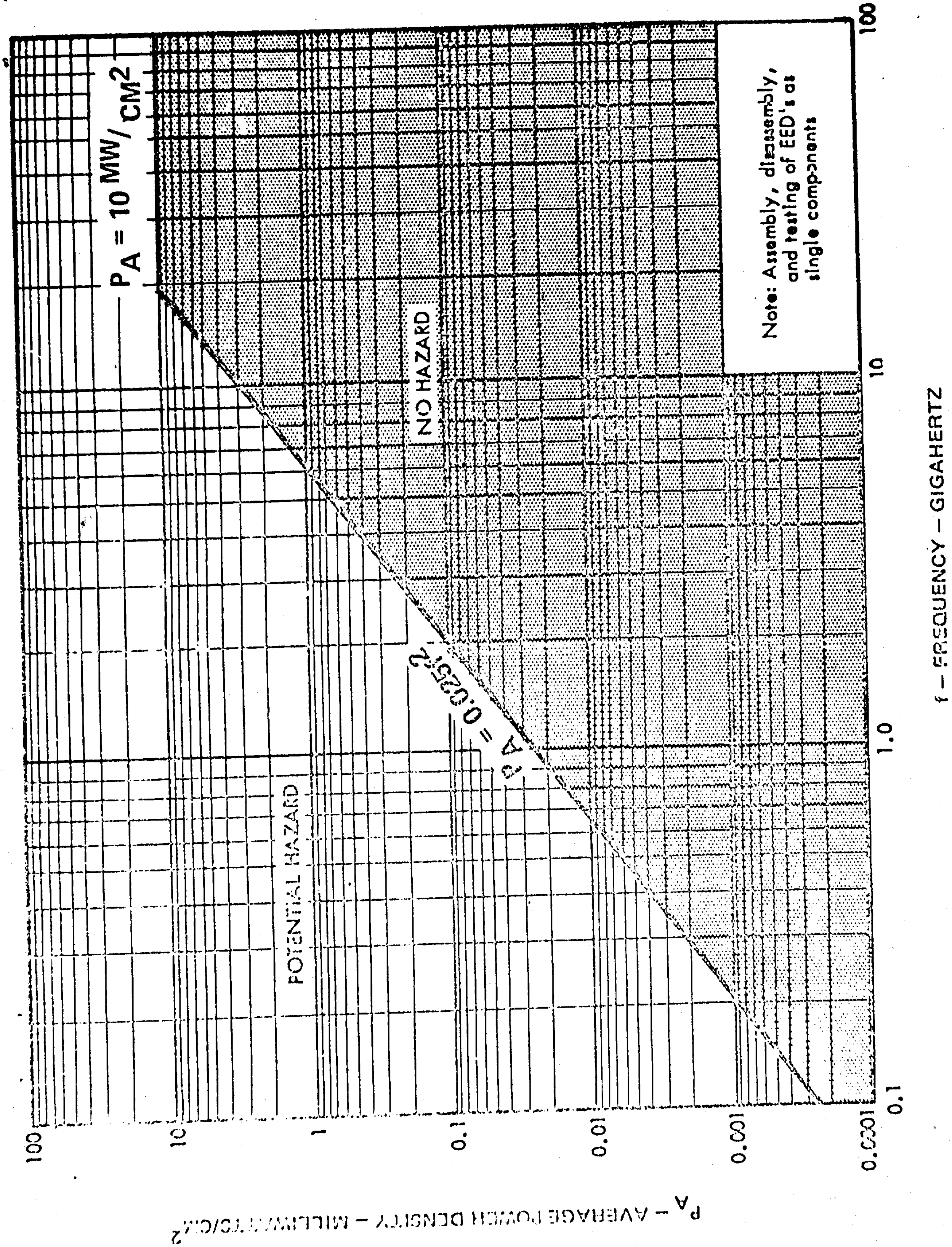


Figure 2-2. Field Intensity Potentially Hazardous to Ordnance in Optimum Coupling Configurations—Radar Frequencies

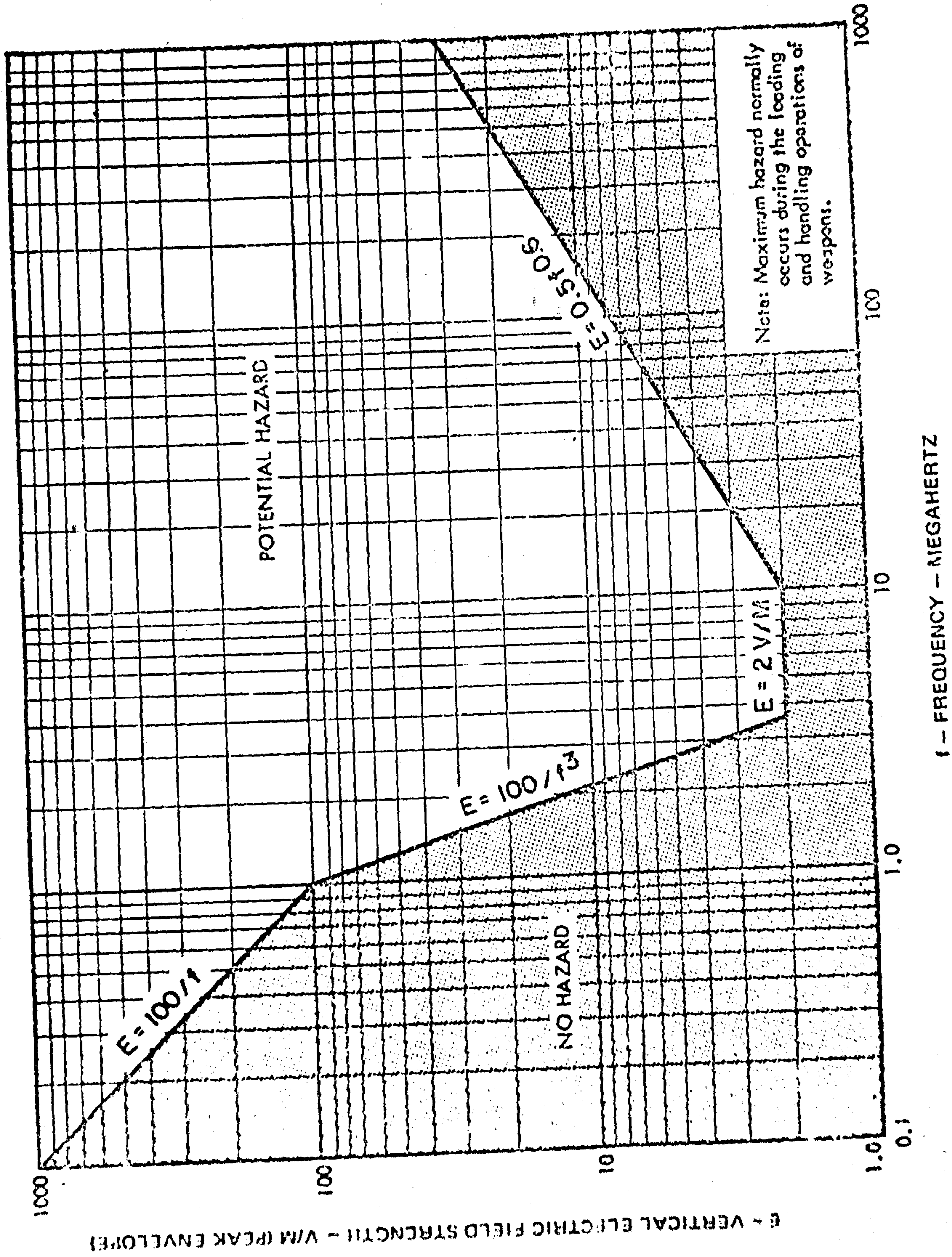


Figure 2-3. Field Intensity Potentially Hazardous to Susceptible Weapons which Require Special Restrictions—Communication Frequencies

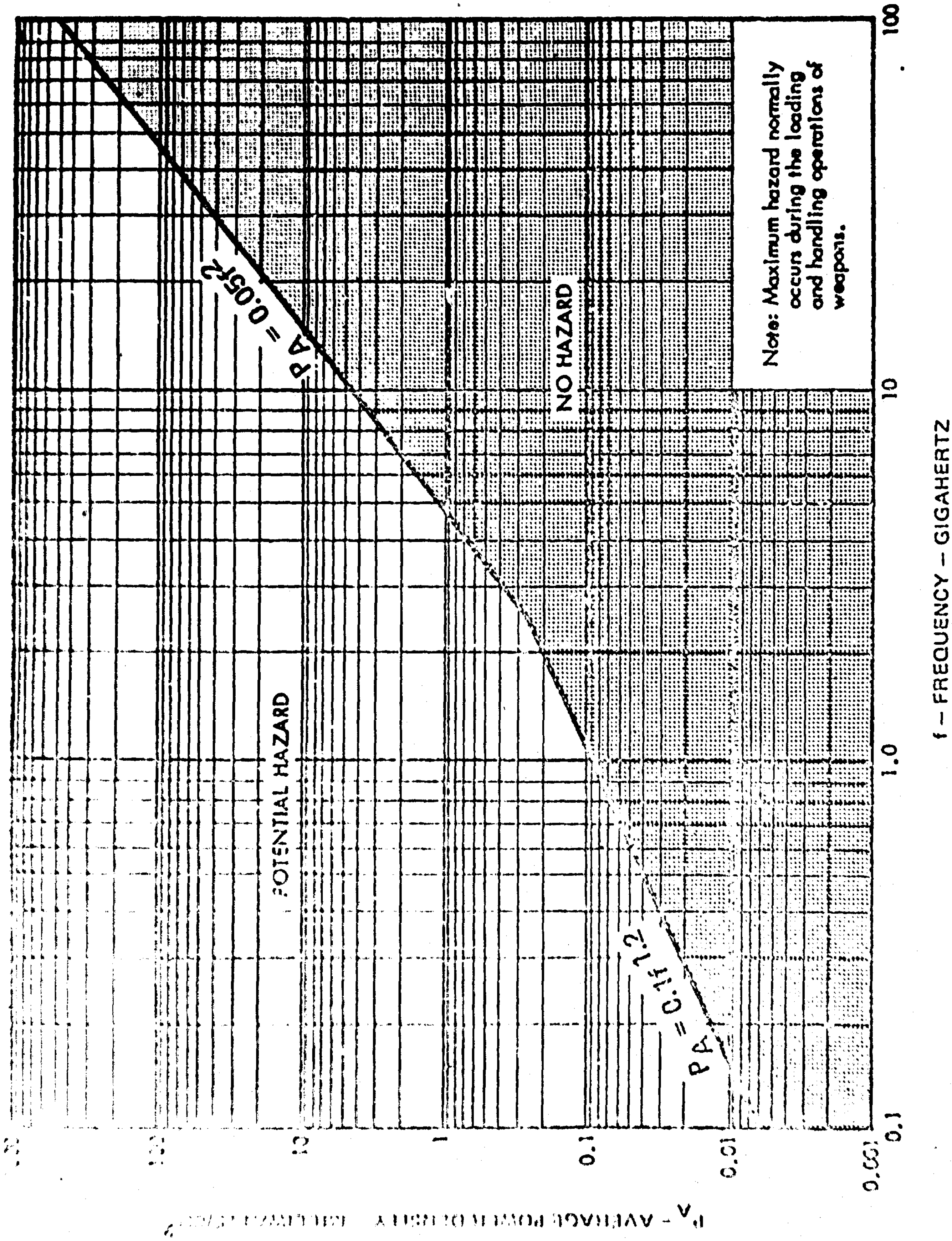


Figure 2-4. Field Intensity Potentially Hazardous to Susceptible Weapons which Require Special Restrictions—Radar Frequencies

Table 2-1. Electromagnetic Environment Levels

Frequency (MHz)	Field Intensity* (Volts (RMS)/ Meter)	Mean Power Density (Milli-watts/Square Centimeter)
Communication		
0.25 - 0.535	300	
2 - 32	100	
100 - 156		0.01
225 - 400		0.01
Radars		
200 - 1215		10
1215 - 1365		5
2700 - 3600		78
5400 - 5900		105
7900 - 8400		175
8500 - 10440		150
33200 - 40000		4

*These intensities apply to the smaller of the following field components:

1. The vertical component of the electric field (E).

2. The directional maximum component of the horizontal magnetic field in ampere turns/meter (H), multiplied by 377 ohms.

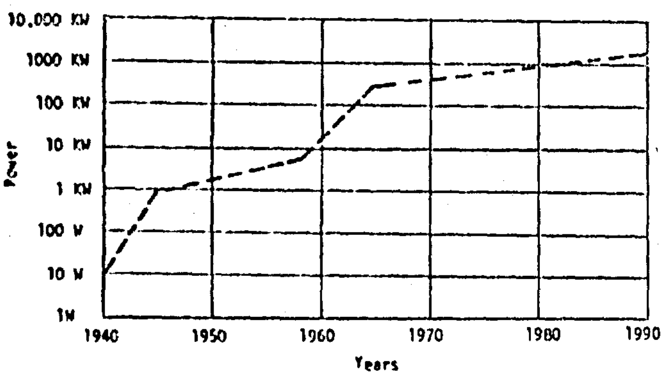


Figure 2-5. Trend in Available Power

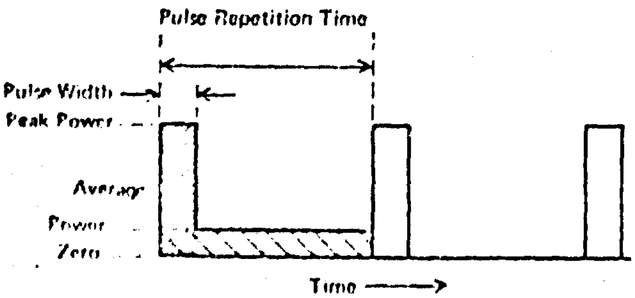


Figure 2-6. Pulse Transmission Relationships

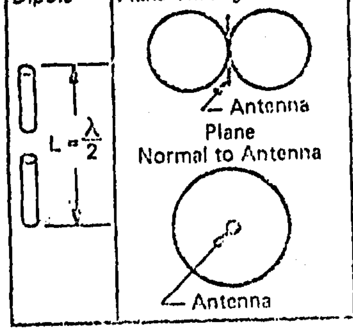
	RADIATION PATTERN	POLARIZATION	GAIN OVER ISOTROPIC
Half-Wave Dipole		Linear – (Coplanar with Antenna)	1.64 (2.15dB)

Figure 2-7. Characteristics of a Half-Wave Dipole

radiation at some point in space. Figure 2-8 shows a feed and reflector system typical of those used in radars, together with the associated radiation pattern.

The fields produced by shipboard antennas are important to the HERO problem because a knowledge of the field strength is necessary for determining the amount and type of protection needed for the ordnance. (See Figures 2-1 through 2-4.) Unfortunately, only in the region where the antenna's field appears as a plane wave, decreasing as an inverse function of the distance from the antenna ($E = f(1/r)$), can any positive measurements be made or field intensity relationship be established. This region is known as the far field or Fraunhofer region. Knowledge of the intensity at one point in this space can lead to an accurate extrapolation of the intensity at another point. It is in this region of an antenna's field that there is also a definite relationship between the electric and magnetic fields. They are related by the equation $E = 120\pi H$.

Even though some areas of a ship are in the far field of an antenna, additional complications are introduced by reflections and discontinuities in the propagating medium. Figure 2-9 depicts typical field strength contours on the deck of an aircraft carrier. The irregularity of the shape of the contours suggests the difficulty of predicting an electromagnetic environment. The contours shown are a measure of the electric field which was generated by a single transmitter feeding one monopole antenna located at the edge of the carrier deck. The change in the pattern which would occur with the addition of another transmitting system is virtually unpredictable.

The place where the far field of an antenna begins is not exactly defined. It is an arbitrarily chosen region where the previously described effects begin to be evident. For small radiators, it is usually considered to begin at a distance of approximately one wavelength from the antenna. For large radiators, $2D^2/\lambda$ (where D is the largest dimension of the antenna) is commonly accepted.

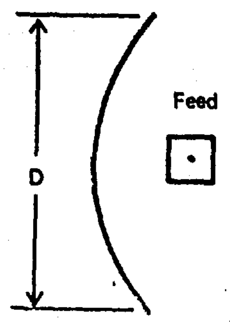
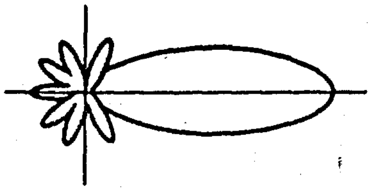
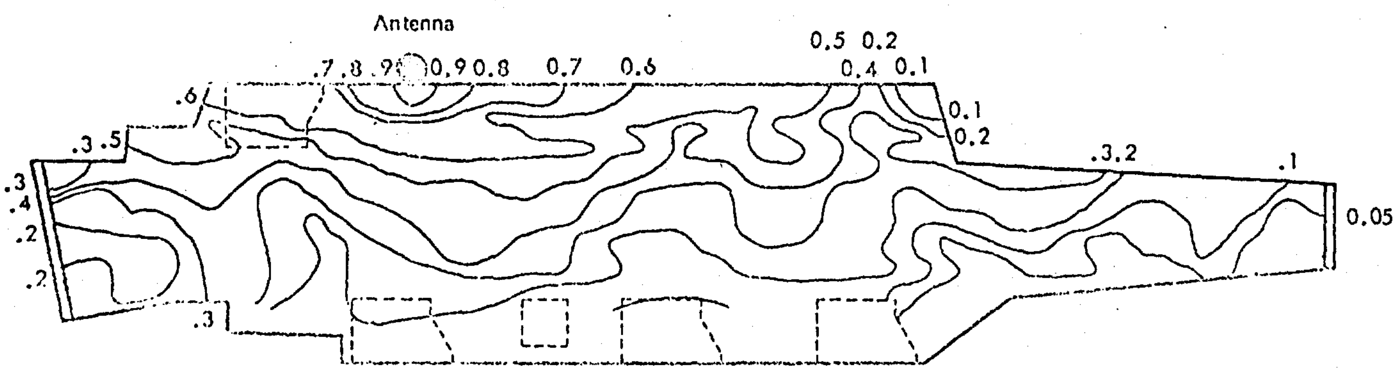
	Radiation Pattern	Polarization	Gain Over Isotropic
Paraboloidal 	Approx. Circularly Symmetrical  Half Power Beam Width $= 70 \frac{\lambda}{D}$ degrees	Determined by feed	20 db to 50 db

Figure 2-8. Characteristics of a Reflector Antenna



Vertical component of the E Field three feet above the deck expressed in volts per meter for one watt radiated power at a given communication frequency.

Figure 2-9. Typical Field Strength Contours on a Carrier Deck

The near field of any antenna is the region or space between the antenna and the beginning of the far field. It is composed of the combination of effects from two regions: the inductive region and the Fresnel region. The inductive region is considered to be significant up to one wavelength from all antennas. The Fresnel region (or interference region) is considered to begin one wavelength from the antenna, and its noticeable effects extend to the beginning of the far field. The near field of shipboard communication antennas is such that there is little effect due to Fresnel interference; consequently, the near field of small radiators is considered to be made up entirely of the induction field.

For shipboard radar antennas, the Fresnel interference is significant and cannot be ignored. Since the induction field is only significant to distances comparable to a wavelength, this usually amounts to no more than a few centimeters for radar antennas. Insofar as HERO is concerned,

the only applicable consideration for radar fields is the Fresnel region, since it is unlikely that ordnance will be employed at the aperture of shipboard radar antennas.

2.5 ELECTROMAGNETIC ENERGY TRANSFER

The power received by an antenna in a uniform field is a function of its effective area and the power density at the antenna location. That is,

$$W_R = A_{er} P_A,$$

where

W_R is the power (watts) delivered to the load impedance across the antenna terminals, and A_{er} is the effective area of the antenna (meters^2).

The effective area of a receiving antenna is given as

$$A_{er} = \frac{G_R \lambda^2}{4\pi},$$

where

G_R = gain of receiving antenna, and

λ = wave length in meters = 300/frequency in megahertz.

This expression is for the maximum effective area of an antenna and it occurs only when the antenna is matched to its load. Therefore,

$$W_R = \frac{G_R \lambda^2 P_A}{4\pi}$$ if the power density at the receiving antenna is known,

or

$$W_R = \frac{G_R G_T W_Y \lambda^2}{(4\pi r)^2}$$ if the power transmitted, distance to transmitting antenna, and gain of transmitting antenna are known.

These equations are valid only when the load is matched to the impedance of the antenna since the expression for A_{er} is for maximum effective area and occurs only when the load and antenna are matched.

The following sample calculation illustrates the principle for determining the induced current in an EED bridgewire which terminates a half-wave resonant dipole antenna. We must assume the following conditions:

1. The lead wire length (AB and DC are arranged so that a half-wave dipole is formed (see Figure 2-10). This antenna is terminated in a one ohm EED.

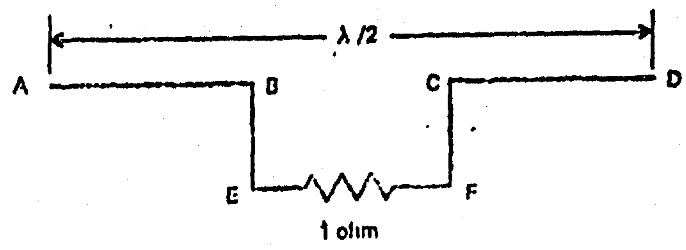


Figure 2-10. An EED Matched to a Dipole Antenna

2. The characteristic impedance and length of the transmission line (formed by BE and CF) are such that the one ohm load is matched to the antenna. The losses of the transmission line are neglected.

3. The antenna gain G_R relative to an isotropic antenna is taken as 1.64 (see Figure 2-7).

4. The field strength is assumed to be 100 volts per meter at 30 megahertz.

Use equation

$$W_R = \frac{G_R \lambda^2 P_A}{4\pi},$$

where

$P_A = E^2/120\pi = 26.5$ watts/meter^2, and

$W_R = 345.8$ watts.

The current in the bridgewire of the EED is calculated from

$$W = I^2 R$$

where

W = power (watts),

R = resistance (ohms), and

I = current (amperes).

Thus, for R = 1 ohm (a typical value for EEDs), we have:

I^2 = W/R = 345.8,

I = 18.6 amperes,

G_R = 1.64, and

λ = 10 meters.

Therefore,

$$W_R = \frac{1.64 \times (10)^2 \times 26.5}{4\pi} \text{ watts.}$$

The induced current in an EED bridgewire as previously calculated represents a worst case situation where all protection normally found in the ordnance, such as shielded cables and shielded enclosures, have been omitted. Also, all losses due to transmission line and impedance mismatches have been ignored. It is a theoretical method for obtaining maximum values. The current in the bridgewire has never been found to exceed the value calculated by this method.

The structural enclosure of an ordnance item provides some electromagnetic shielding for the enclosed EEDs. In actual conditions found in ordnance, the problem of analyzing the details of the complete mechanism of the transfer of energy from the electromagnetic environment to an EED does not lend itself to a straightforward theoretical solution. However, it is unlikely that the worst case example could occur in the complete ordnance.

The exterior of the ordnance may be energized either by incident fields from external sources or by direct coupling from its own internal sources. Whatever the source, the surface distribution of current and charge may exhibit stationary patterns depending on the method of excitation, the wavelength of the excitation current, and the geometry of the ordnance. These patterns are usually very complicated.

In electrical and mechanical form, the receiving antennas of the ordnance that contribute to the HERO problem are not necessarily recognizable as antennas. They may be the aircraft, launchers, umbilical cables, access doors and hatches, or discontinuities in shields, but they nevertheless function as linear antennas, current loops, or cavity and slot aperture antennas.

Some of the ways in which umbilical cables, apertures, and discontinuities in the shield can function as receiving antennas for electromagnetic energy are shown in Figure 2-11. Panel (a) illustrates an umbilical cable as the receiving antenna (vertical or loop) and an internal loop antenna consisting of an EED and its associated wiring. External cables can act as effective receiving antennas when exposed to an electromagnetic environment permitting the transfer of rf current into the ordnance which can couple directly or inductively into an EED bridgewire. This type of receiving antenna can be an effective receiver of communication frequencies, depending on the length of the [illegible] and their connections.

[illegible] (b) and [illegible] of Figure 2-11 illustrate [illegible] ordnance [illegible] acting as receiving [illegible] apertures are effective receiving [illegible] cavity [illegible] often [illegible] energy is coupled from [illegible] cavity to the bridgewire [illegible]

Panel (d) illustrates energy transfer occurring as a result of an arc. When connection is either made or broken between any two ordnance elements having different electrical potentials (e.g., connectors between ordnance and launcher or between ordnance and test equipment), arcs occur which can produce large amounts of energy at all frequencies including dc and low frequency ranges. If arcs occur in the firing circuits, this energy can be delivered to an EED even if the EED is protected by an EMI filter (see Chapter VI).

Under any of the conditions illustrated in Figure 2-11, the energy transfer can be increased by the presence of personnel in close proximity to the ordnance. The human body displays receiving antenna characteristics and can thus increase the efficiency of the transfer path of electromagnetic energy to the susceptible portions of the ordnance.

Attempts to analyze the amount of energy coupling by a theoretical study of apertures, lead-to-lead intercoupling, lengths of wires, impedance match or mismatch, and effectiveness of shielding have all failed, due to the complexity of the problem.

2.6 MEASUREMENTS

The parameters used to describe the electromagnetic environment are generally:

E = electric field (volts/meter),

H = magnetic field (ampere turns/meter), and

P_A = power density (watts/meter^2).

The polarization of a radiating source is defined in terms of the orientation of the electric field with respect to a reference plane (usually the surface of the earth). Accordingly, the polarization is not restricted to linear polarization in the horizontal and vertical planes of propagation but can contain both horizontal and vertical components, establishing elliptical polarization.

The magnetic field is not restricted to any one plane of propagation, but follows the polarization forms of the electric field.

The instantaneous power flow per unit area from a radiating source may be represented by the Poynting vector:

$$P_I = \bar{E} \times \bar{H}.$$

To determine the outward power flow from a given radiator at a point in space, the preceding expression must be integrated over a complete cycle. The form most useful in calculating the power

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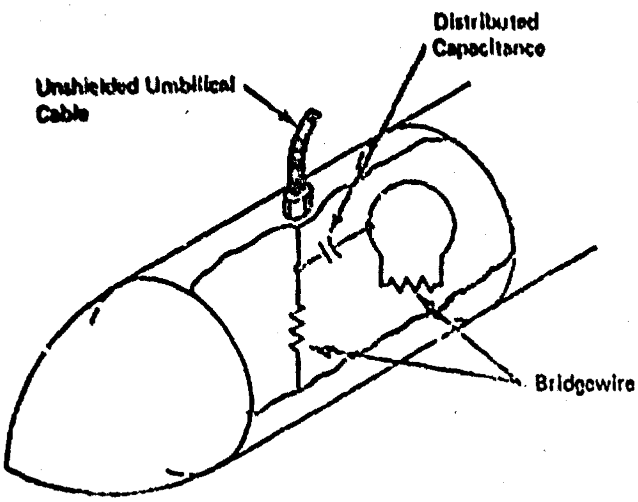
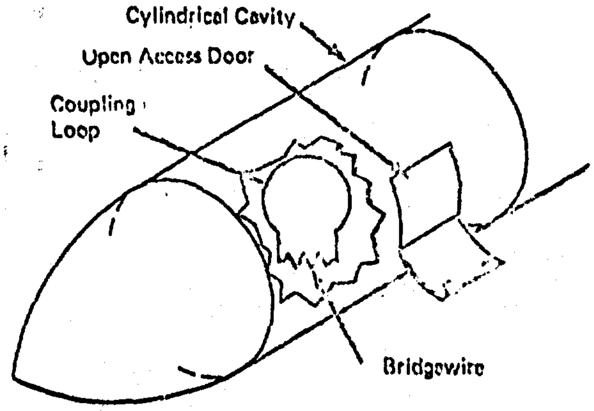


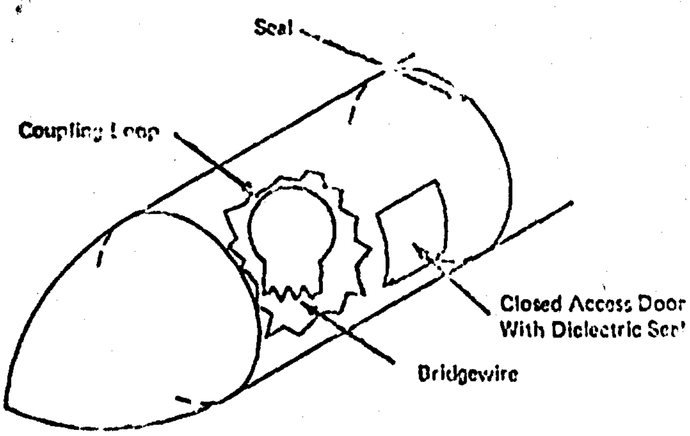
(a) Vertical or Loop Antenna

Unshielded umbilical cables form vertical or loop antennas coupling energy directly or by induction to bridge wire.



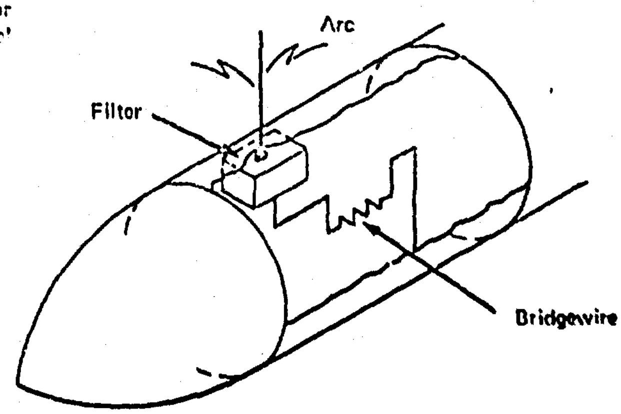
(b) Aperture Antenna

Open access door forms aperture antenna coupled to cylindrical cavity, internal wiring forms loops or probes to couple energy to bridge wires.



(c) Slot Antenna

Dielectric filled gaps form slot antennas coupling energy into weapon.



(d) Conduction of RF Arc

The RF arc striking an unprotected EED lead can cause low frequency and DC currents to flow in the EED circuit even though the filter is used for protection.

Figure 2-11. Ways in Which Ordnance Components Can Function As Receiving Antennas

density of a source of radiation is the complex Poynting vector

$$P_A = 1/2 \, \mathrm{Re} \, (\bar{E} \times \bar{H}^*),$$

where $\bar{H}^*$ is the complex conjugate of $\bar{H}$.

In the far field of a radiation source, $\bar{E}$ and $\bar{H}$ are transverse to the direction of propagation and are complicated only by the nature of their polarization, which may consist of both vertical and horizontal components. In the near field, $\bar{E}$ and $\bar{H}$ are further complicated by having components that are not transverse to the direction of propagation and by the existence of the reactive fields of the radiation source.

Field measuring devices can be divided into three basic categories: (1) those sensitive to the electric component, (2) those sensitive to the magnetic component, and (3) those sensitive to the power density. An ideal measuring device would be sensitive to the power density and capable of summing the contribution of all field components at the point of measurement. Since this ideal is not easily realized, the measuring techniques must compensate for the limitations in measurement devices.

At communications frequencies, it is common to use field measuring equipment that indicates either the electric field intensity E (volts/meter) or the magnetic field strength H (ampere turns/meter). At radar frequencies, it is common to use equipment that measures power density. Although the above is not an absolute rule, the types of detectors and their frequency characteristics have made it convenient.

Some measuring devices employ electric or magnetic field detectors and electronically convert the indication to power density or to the unmeasured electric or magnetic component of the field. It must be remembered that the conversion of E or H directly to P_A is valid only when the relationship between E and H is known. The relationship of E/H in the near field is not known and is unmeasurable.

Chapter III.

ELECTROEXPLOSIVE DEVICES

3.0 GENERAL

Electroexplosive devices (EEDs) are used extensively in naval ordnance for a wide variety of applications (see Table 3-1). They can take a large number of different configurations but their essential nature remains the same. A schematic diagram of a hot bridgewire (HBW) EED, the type most commonly used, is shown in Figure 3-1. An EED of this type is normally initiated by heating the bridgewire with an electric current thus initiating the primary charge surrounding it. The primary charge sets off the booster charge, which in turn sets off the main charge. Although some types of EEDs that utilize bridgewires are initiated by shock waves produced by the vaporization of the bridgewire, heat is the most commonly used method of initiation.

An EED is defined as "an electric initiator or other component in which electrical energy is used to initiate an explosive, propellant, or pyrotechnic material contained therein". The energy source used to initiate this device is normally an ac or dc firing circuit. However, by the nature of the device, any electrical energy, including electromagnetic energy conducted to the device from the environment that the weapon may be in, can initiate it. This is the basic HERO problem. Since the HERO problem stems from the use of EEDs, they should not be used in ordnance unless non-electric devices or other electric devices, which are equally reliable and effective, are not available.

This chapter describes the manner in which EEDs function and discusses the susceptibility of

Table 3-1. Typical Applications of EEDs

Rocket Ordnance
Ignition systems for solid and liquid propellant rockets
Explosive actuation of battery systems
Explosive mechanical detents
Detonators for warheads
Guided Missiles
Ignition systems for solid and liquid propellants
Explosive actuation of relays, switches, and valves
Self-destruct systems
Power for electric generators
Power for gyroscopic guidance systems
Power for control surfaces
Separation of nose cones
Inflation of flotation bags for recovery systems
Detonations for warheads
Aircraft
Jettison of wing tanks, pods, and cargo
Ejection of bombs, seats, rockets, and canopies
Launching of rockets and missiles
Launching of aircraft
Actuation of emergency hydraulic systems
Starter units for jet engines
Fuzes for bombs, rockets, and missiles
Primers for gun ammunition
Shipboard
Primers for large gun ammunition
Fuzes and charges for mines, depth charges, and torpedoes

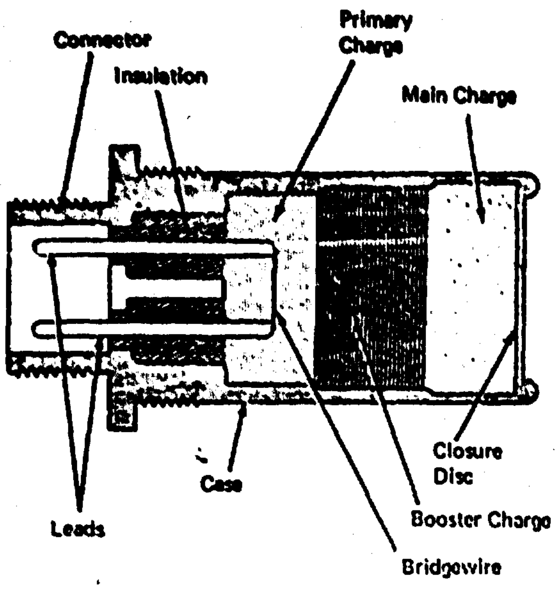


Figure 3-1. Schematic Diagram of Hot Bridgewire EED

such devices to electromagnetic energy. The advantages and disadvantages of representative types of available EEDs are indicated. The purpose is (1) to give the designer background information essential to an understanding of the HERO problem as it relates to EEDs, and (2) to assist him in selecting an EED that is suited both to the requirements of his weapon and the requirements of HERO.

3.1 TYPES OF HAZARDS

(1) Inadvertent Initiation

One of the adverse effects of electromagnetic energy on a weapon is the inadvertent initiation of the EED. This can cause the weapon to operate prematurely in its design mode, thus creating a safety problem. If the EED fires either out of sequence in a prescribed order of EED firing or before the weapon is armed, the weapon can be dudded or reduced in effectiveness.

(2) Dudding of EED

Heat generated by electromagnetic energy in the area of the bridgewire, even though it may be insufficient to ignite the primary explosive, can appreciably reduce its sensitivity. If continued over a period of time, this heat can make the primary mix so insensitive that the EED cannot be fired. It can also burn out the bridgewire rendering the EED useless. This hazard, called dudding of the EED, is as undesirable from a reliability standpoint as inadvertent initiation.

(3) Thermal Stacking

In pulsed electromagnetic environments such as radar, there occurs a phenomenon called "thermal stacking" which can increase the likelihood of inadvertent initiation or dudding. The heat generated by a single pulse of energy may be insufficient to initiate the EED, but if the time between pulses is shorter than the thermal time constant of the bridgewire, successive pulses can progressively elevate the bridgewire temperature until the initiation temperature is reached. Figure 3-2, in which the heat increase is shown graphically, demonstrates that the temperature will rise from the ambient level until it reaches a final equilibrium point, after which no further increases will occur. This final temperature, which is a function of pulse amplitude, pulse duration, repetition rate (duty ratio), and the thermal time constant, may be sufficiently high to cause dudding or even to initiate the EED. In considering the hazard in pulsed environments, the effects of thermal stacking must be considered. The maximum safe power densities indicated by Figures 2-2 and 2-4 take into account the effect of thermal stacking.

3.2 MODES OF RF EXCITATION

There are two modes of rf excitation in an EED; the differential mode and the coaxial mode. In the differential mode, the two-wire firing leads are balanced and the electromagnetic energy propagates to the EED between the two wires in the same manner as the normal ac or dc firing current. This will cause joule (resistance) heating of the bridgewire, thereby causing inadvertent initiation or dudding of the EED. Figure 3-3 illustrates the differential mode of excitation. In this mode it might appear that if a large mismatch of impedance occurs between the EED and the transmission line, which is usually the case, most of the electromagnetic energy would be reflected at the EED. Although most of the energy is reflected, enough can be transmitted to produce a hazardous condition.

In a coaxial firing system, the energy propagates between two concentric conductors. The center conductor is a wire or metal rod and is contained inside a cylindrical conductor, such as a shield, that is concentric with it. For this type of firing system the coaxial mode of rf excitation is obvious and the energy transmitted will cause joule heating in the bridgewire just as the ac or dc firing current does. (Figure 3-4).

The coaxial mode can also be established on a two-wire balanced shielded system. In this case the two lead wires serve as the center conductor and the shield serves as the outer one (Figure 3-5). In a two-wire balanced system, energy transferred to the EED in the coaxial mode will cause a high potential to be developed from the bridgewire, through the explosive mix, to the EED case. This can cause arcs to occur in the explosive mix or can cause dielectric heating of the mix. The coaxial mode can be established on a two-wire system through a high impedance connector or a break in the shield.

3.3 DESIGN FACTORS AFFECTING EED SELECTION

In selecting an EED for use in a weapon, the designer should be aware of the inherent design

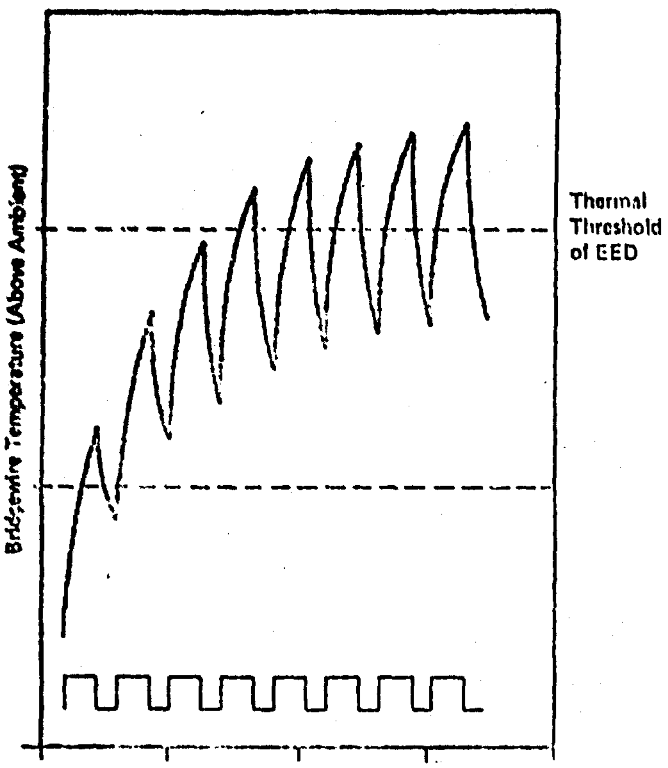


Figure 3-2. Temperature Increase Due to Thermal Stacking

features of the various types of EEDs as they affect the weapons susceptibility in the electromagnetic environment. Brief descriptions of the types of EEDs presently available to the designer with a discussion of methods of determining EED sensitivity are provided in paragraphs 3.4 and 3.5.

3.4 AVAILABLE TYPES OF EEDS

(1) Hot Bridgewire Devices

The type of EED most widely used at the present time is the hot bridgewire (HBW) device. Four common HBW circuits are shown in Figure 3-6. Types A and B are generally preferred for HERO use, while the use of C and D is generally discouraged.

The one ampere/one watt requirement of MIL-I-23659 B(AS) for the HBW device may serve to reduce the hazard from electromagnetic energy in proportion to the increase in the power required to fire the EED. However adherence to this requirement alone will not solve the HERO problem. It is apparent from the maximum safe field curves (Figures 2-3 and 2-4) and the maximum environmental levels (Table 2-1) that the potential hazard could not be eliminated for some weapons systems even if one ampere/one watt EEDs were used in these systems.

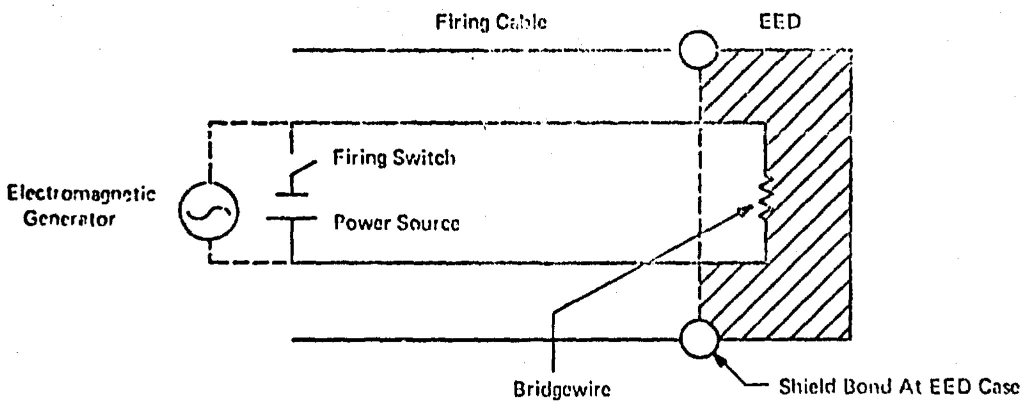


Figure 3-3. Differential Mode of RF Excitation in a Two Wire Firing System

Selection criteria for a one ampere/one watt EED should consider design techniques used by the manufacturer to conform to the no-fire stimuli requirements of MIL-I-23659 B(AS). Occasionally the heat dissipation requirements of such an EED are achieved by introducing metallic materials into the explosive mix or baseplug of the device. The presence of these materials may provide a common mode current path for electromagnetic energy from a firing lead through the explosive mix or baseplug to the case of EED. The device may be more sensitive to electromagnetic energy through this mode than to the intended (pin-to-pin) firing mode.

(2) Exploding Bridgewire (EBW) Devices

The physical appearance of an exploding bridgewire (EBW) is similar to that of the more conventional HBW type. The major difference is the absence of the sensitive primary explosive on the bridgewire. The operation of the EBW utilizes thermal and mechanical phenomena that result from

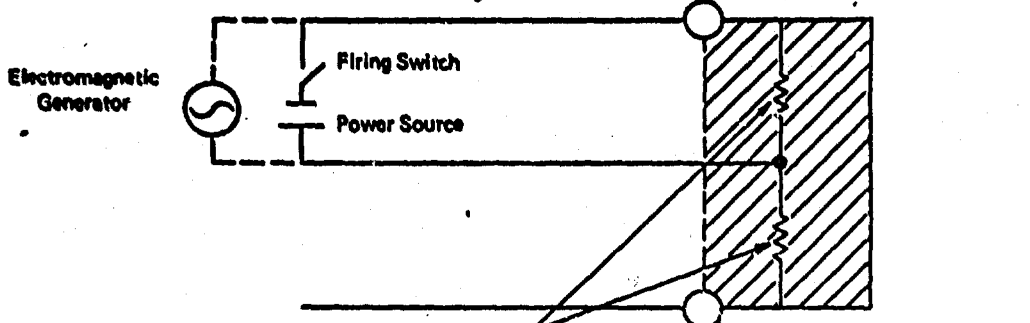


Figure 3-4. Coaxial Mode of RF Excitation in a Coaxial Firing System

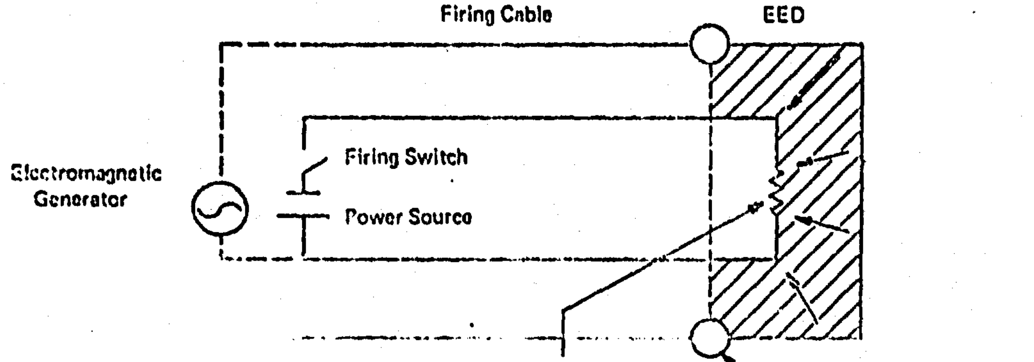


Figure 3-5. Coaxial Mode of RF Excitation in Two Wire Firing System

the dissipation of a large amount of electrical energy that has been rapidly applied to the bridgewire. The exploding bridgewire directly initiates a secondary explosive such as PETN or RDX. This elimination of the primary explosive greatly reduces the sensitivity of the EBW. In order to initiate an EBW, a current in the order of thousands of amperes must be applied in microseconds. It would be unlikely for this to happen accidentally in any electromagnetic environment; therefore, the hazard of inadvertent initiation is considered small. However, a current insufficient to initiate the device can burn out the bridgewire, thus dudding the EBW.

The advantage of decreased sensitivity in the EBW is offset to some degree by the complexity of the firing system.

(3) Conductive Mix EEDs

In the conductive mix EED, the firing current is carried by the explosive mix rather than by a bridgewire. The current path is a powdered conductive material, usually graphite, mixed with primary explosive. Electrical current is passed between the leads through the conductive-explosive mix. The flow of current causes "hot spot" heating that brings the explosive mix to its initiation temperature.

The voltage required for firing a conductive mix EED varies from 10 to 50 volts. Firing times (three to ten microseconds) are much shorter than for HBW devices because the thermal time constant is much smaller. The energy requirements are small (as low as ten ergs).

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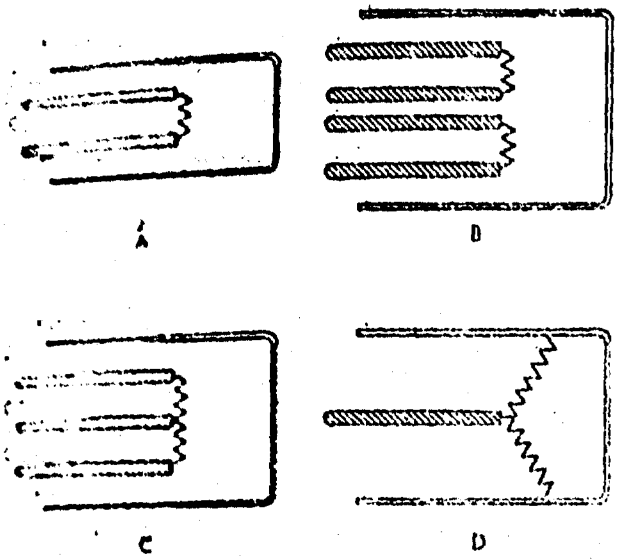


Figure 3.6 Four Types of Hot Bridgewire (HBW) EEDs

A number of design problems are associated [illegible] the conductive mix EED. These problems are [illegible] in the quality control and production of [illegible] EED rather than in theoretical concepts of de[illegible] The resistance of the mix varies widely with [illegible] of the mixture of explosive and [illegible] particles. The resistance is usually in [illegible] order of hundreds of ohms and seems to be [illegible]larly well matched to the induced rf currents. [illegible], conductive mix EEDs are not recom[illegible] for use by the Navy at this time.

(4) Carbon Bridge EEDs

In the carbon bridge EED, the metal [illegible] wire is replaced by a conducting bridge of [illegible]. Colloidal graphite serves as a bridge [illegible] two closely spaced electrodes. The graphite particles form a resistance element that varies from a few hundred ohms to as high as ten thousand ohms; thus, the voltage sensitivity of the carbon bridge EED varies considerably among supposedly identical units. The carbon bridge EED has been found to be very sensitive to induced electromagnetic energy. MIL-I-23659 B(AS) states that carbon shall not be used as bridge material. From the HERO standpoint, it is recommended that the designer avoid electroexplosive devices having carbon bridges.

3.5 SENSITIVITY MEASUREMENT

In addition to selecting an EED of a suitable type, the designer must know its firing sensitivity. The various types of EEDs now available are usually classified by their current sensitivity. Maximum No-Fire has been established as "the greatest firing stimulus which does not cause initiation, within five minutes, of more than 1.0 percent of all electric initiators of a given design, at a 95 percent confidence level."

The statistical test commonly used to determine current sensitivity is the Bruceton Test. This test yields an excellent estimate of the mean, but a poor estimate of the standard deviation. When an EED supplier or manufacturer gives no-fire characteristics, the weapon designer should determine what method was used to obtain these characteristics before they are accepted.

In general, the designer is given a requirement for an EED which will perform a certain function within a specified time after the application of the firing stimulus. Also, a certain reliability requirement is attached to the performance of this function. The obvious approach to fulfilling these requirements is to use the largest power source allowed by the system in conjunction with a sensitive EED. However, in designing with HERO in mind, the least sensitivie EED should be used.

Chapter IV.

FIRING SYSTEM DESIGN

4.0 GENERAL

Many of the weapons that are used by the Navy have subsystems and firing systems that are exterior to the weapon. These exterior systems, together with their connecting circuitry, can augment the HERO problem. The design of ordnance that meets the HERO requirements, requires that the effect of the electromagnetic environment on the system as a whole be considered for all situations that the weapon is expected to encounter in its stockpile-to-launch sequence. There are many situations during this sequence in which electromagnetic energy can enter the weapon. This energy must be excluded at all times if the weapon is to be HERO safe. In addition, the weapon must be designed so that the handling, loading, and testing techniques that must be used do not create additional HERO problems.

The design of the firing system is of particular importance in reducing the susceptibility of the ordnance to the electromagnetic environment. Because the firing system provides the path for transferring the firing energy to the EED, it can also provide the path for transferring electromagnetic energy to the EED. Only in a few types of ordnance will the firing circuit be completely contained within the structure so that the required level of shielding effectiveness is provided by the metallic skin. When the level of shielding effectiveness provided by the system is not sufficient to preclude HERO, the designer will need to utilize the firing system design practices discussed in this chapter.

4.1 FIRING SYSTEMS

A firing system, for the purpose of this discussion, consists of a power source, transmission lines, and all control and switching circuits required to control and transfer power to the bridgewire of an EED. Figure 4-1 illustrates the basic elements of a typical firing system. All firing systems can be divided into two basic categories: (1) low voltage systems used to initiate HBW EEDs, and (2) high voltage systems used to initiate EBW EEDS. There are many variations of these two types. Firing techniques can vary from a simple switch closure to sophisticated coded-pulse systems. The exact nature of the mechanism used to initiate the EED in any type of ordnance is usually dictated by the mission or specific ordnance application.

Electromagnetic sources with frequencies above 10 KHz should not be used to provide the initiating energy for EEDs. If a coded firing system is used, the receiving equipment as well as the firing system must be protected from the electromagnetic environment. The receiving equipment must not permit false indications during exposure to the environment since this might result in premature EED initiation and possibly ordnance actuations.

4.2 FIRING SYSTEM DESIGN PRACTICE

Poor wiring practices are prime factors contributing to the coupling of electromagnetic energy into a firing system. Among the areas in which this commonly occurs are circuit configuration and cable routing. Figure 4-2 illustrates poor wiring techniques from the HERO standpoint. The launch tube is insulated from the launcher pod and serves as one of the firing contacts. One lead of the EED is connected to the weapon skin and hence to the launch tube by a contact spring when the weapon is loaded. The other side of the EED is brought out of the weapon to a firing button, which is electrically connected to the launcher pod. This configuration is particularly susceptible during any handling and loading operation. If personnel touch the weapon skin after the firing leads are connected, electromagnetic energy can be coupled from the aircraft through the EED to the deck. This firing circuit design is basically hazardous. If the weapon were to be made HERO safe, the firing circuit would have to be redesigned. Firing circuits should always be a two-wire balanced system isolated from ground so that no direct path for electromagnetic energy to the EED exists during handling or loading of the weapon.

Improper routing of firing circuit wiring or cables can cause the weapon to be HERO susceptible. All firing circuit wiring should be isolated from other wiring and cables in the system to prevent coupling energy from one circuit to the other.

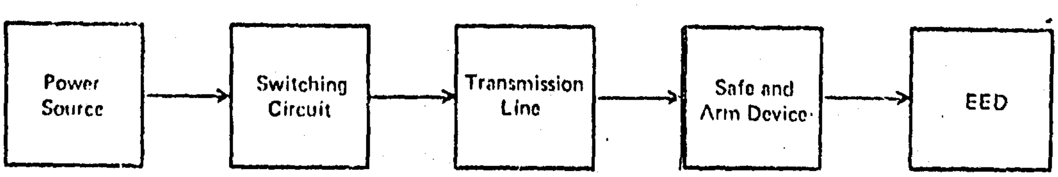


Figure 4-1. Basic Elements of Firing Systems

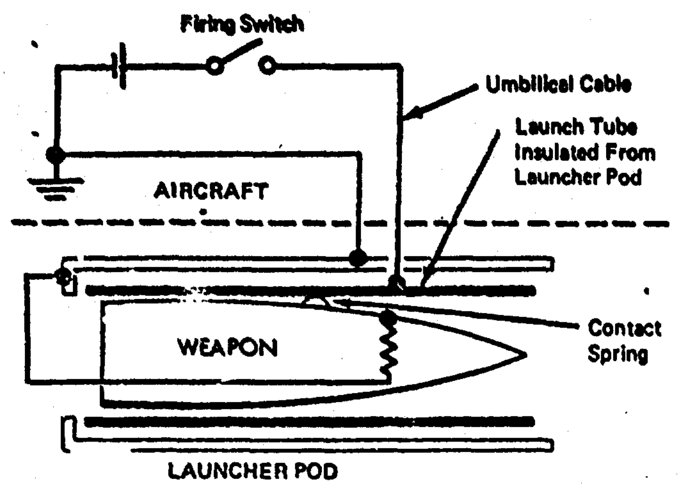


Figure 4-2. Improper Firing System Wiring

Coupling between circuits exists when the current flowing in one circuit produces a current in the other. The mutual elements which can couple energy are resistance, inductance, capacitance, or any series or parallel combination of these elements. An example of coupling possibilities is suggested in Figure 4-3. Coupling can be prevented by shielding each circuit, or to a lesser degree, by the physical separation of the wiring (see Figure 4-4). To prevent energy from the electromagnetic environment from coupling into the wiring within a shielded enclosure, circuit conductors shall not pass through holes in the shield unless shielded as described in Chapter V. Also, conductors shall not pass within one inch of holes in the shield and these holes shall be no greater than 1/4 inch in diameter. This is illustrated in Figure 4-5.

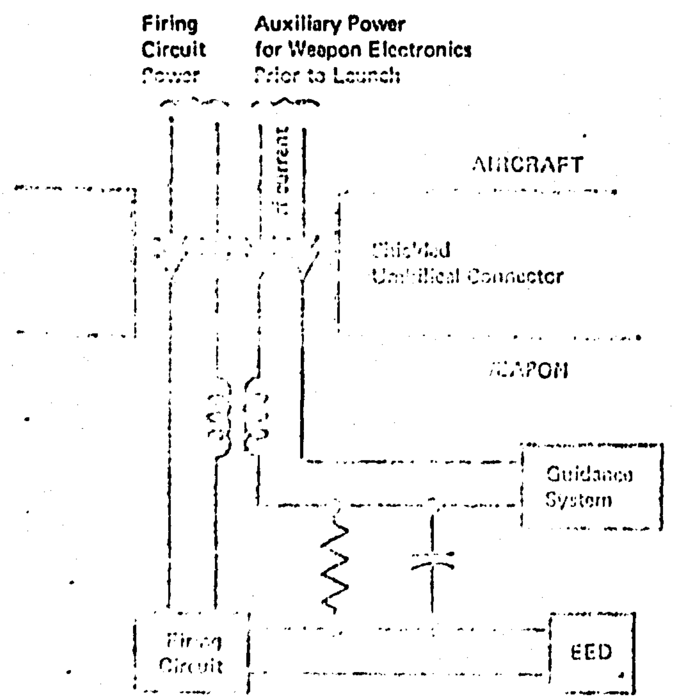


Figure 4-3. Mutual Coupling Between Cables

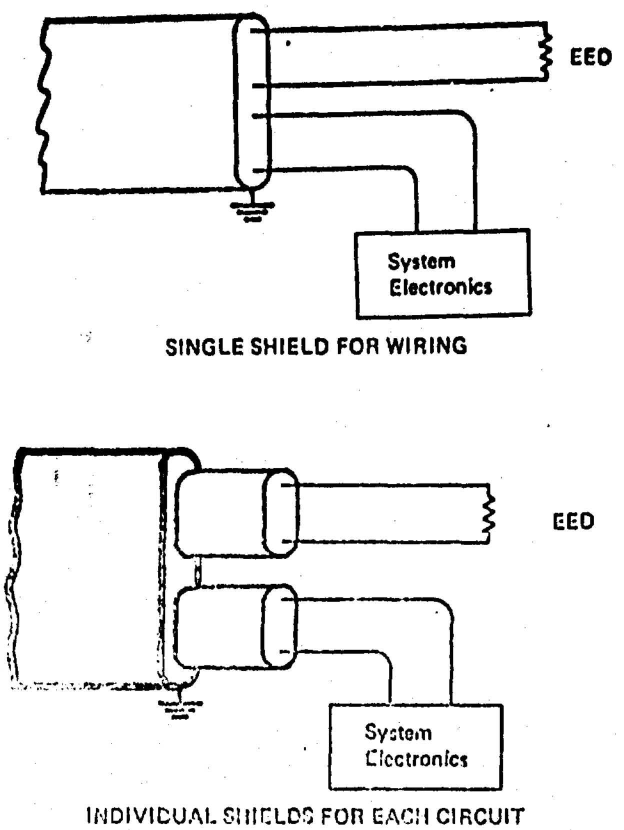


Figure 4-4. Single Common Shield and Individual Shields

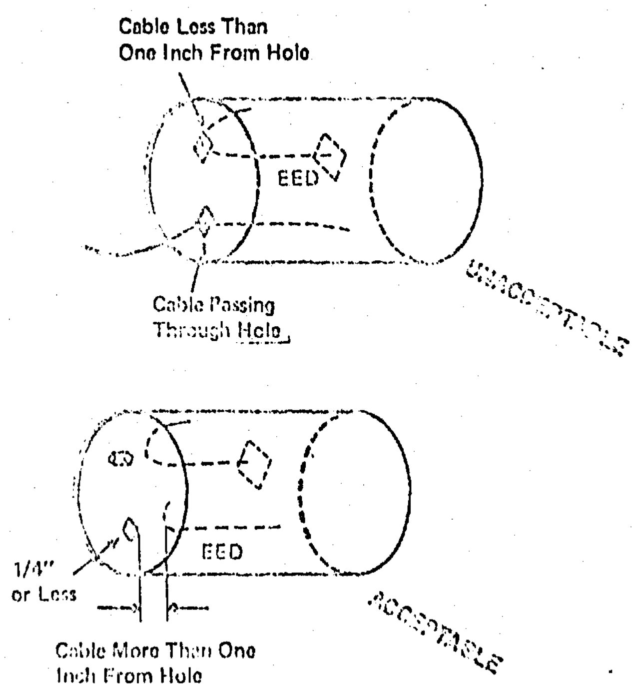
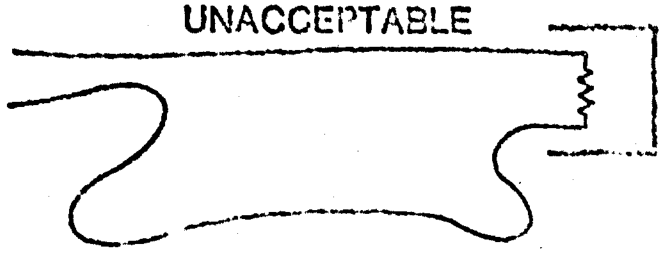


Figure 4-5. Holes in Partially Shielded Weapon Sections

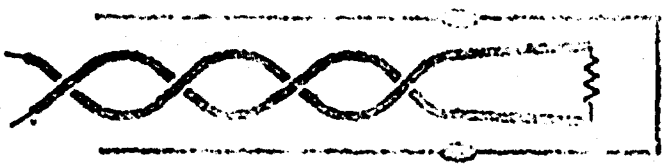
EED firing circuit wiring should be as short as possible and the leads equal in length to minimize induced voltages, as shown in Figure 4-6. The firing circuit leads should be twisted uniformly to reduce the effective area of the pickup loop created by them and to cancel the voltage that may be induced.

UNACCEPTABLE



Unequal Lead Lengths

ACCEPTABLE



Twisted Shielded Pair

Figure 4-6. Unequal Lead Lengths and Twisted Shielded Pair

Caps or shorting plugs are required during storage on many weapons for protection from static charges. From the HERO standpoint, caps are preferred to shorting plugs because a cap has no actual connection to the firing circuit. The cap should be conductive so that it completes the shield when it is installed. In some cases a shorting plug can actually increase the susceptibility of the weapon to electromagnetic energy by creating a loop antenna with the EED circuit. Also during its removal and replacement, it can provide a path for rf currents to flow to the EED circuit. Shorting plugs can be designed so that they reduce the HERO problem (Figure 4-7). They must be constructed of conductive material and designed so that during installation, the shield makes and maintains peripheral shielding contact prior to the shorting of the firing circuit. Also, a good insulating coating on all exposed surfaces of the plug will add additional protection during installation and removal. The thicker this insulation is, up to approximately 1/4-inch, the more protection it will provide, particularly in the hazardous 2 to 32 megahertz region.

Some multistage weapons require exhaust ports for venting the engine exhaust generated during stage separation. These exhaust ports are permanent apertures in the weapon shield; therefore, all cabling and components of the firing system in this section of the weapon must be carefully shielded and filtered to preclude HERO.

If sections of the weapon are non-metallic, all cables and wiring in the firing system that pass through this section must be properly shielded and filtered to preclude the HERO problem. Non-metallic housings, such as fiberglass and plastic, do not afford any protection to the firing system.

4.3 SAFE AND ARM DEVICES

Figure 4-8 is an example of a typical HBW firing system that includes an electrical safe and arm device. In this example, the firing leads between the power source and the EED are opened and the EED leads are shorted to ground by the safe and arm switch. The open contacts in a properly filtered firing system will provide protection from arcs that might cause initiation during the loading and handling operations. The arming process causes the switch sections to move, removing the short to ground from the EED leads and connecting the EED leads to the firing circuit. The ordnance is thereby armed and ready for firing.

A mechanical safe and arm device such as shown in Figure 4-9 is often used to misalign the explosive train when in the safe condition. It does not solve the HERO problem because the EED is not affected either mechanically or electrically by the functioning of the device. Thus the EED can still be inadvertently initiated or dudded by electromagnetic energy. This type of device is used primarily for safety reasons and is often combined with the electrical safe and arm device.

In some cases, an EED may be used to provide the mechanical energy to operate the safe and arm device. EEDs used for this purpose must be protected from the environment because their inadvertent initiation can cause the weapon to be armed at an undesirable time.

4.4 HERO PROBLEMS OF FIRING SYSTEMS

Examples of firing system designs that cause ordnance to be HERO susceptible are given in this section. These examples are based on actual weapon design, and the expedients discussed are considered interim measures (retrofits) allowing ordnance to remain operational in present electromagnetic environments. They are not considered as having completely solved the HERO problem or as having rendered unsatisfactory ordnance designs completely satisfactory.

Aircraft and surface launched weapons pose the greatest hazard because they must be handled and loaded in high level electromagnetic environments, and they generally have subsystems or firing systems that are exterior to the weapon. Underwater launched weapons are not usually exposed to the high level environments, and the nature of their designs is such as to provide more protection from the environment than is provided by either air or surface launched weapons. They can be exposed, however, to high level environments, particularly when they are being transferred to a ship or submarine.

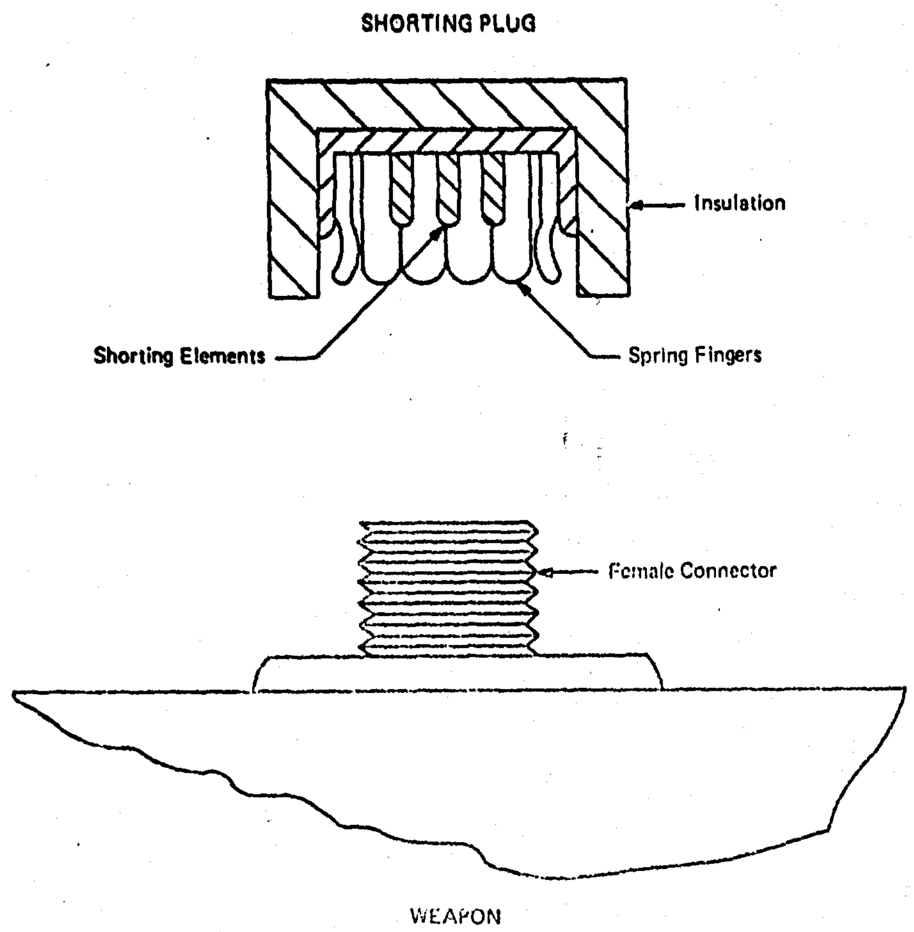


Figure 4-7. Shorting Plug for Weapon

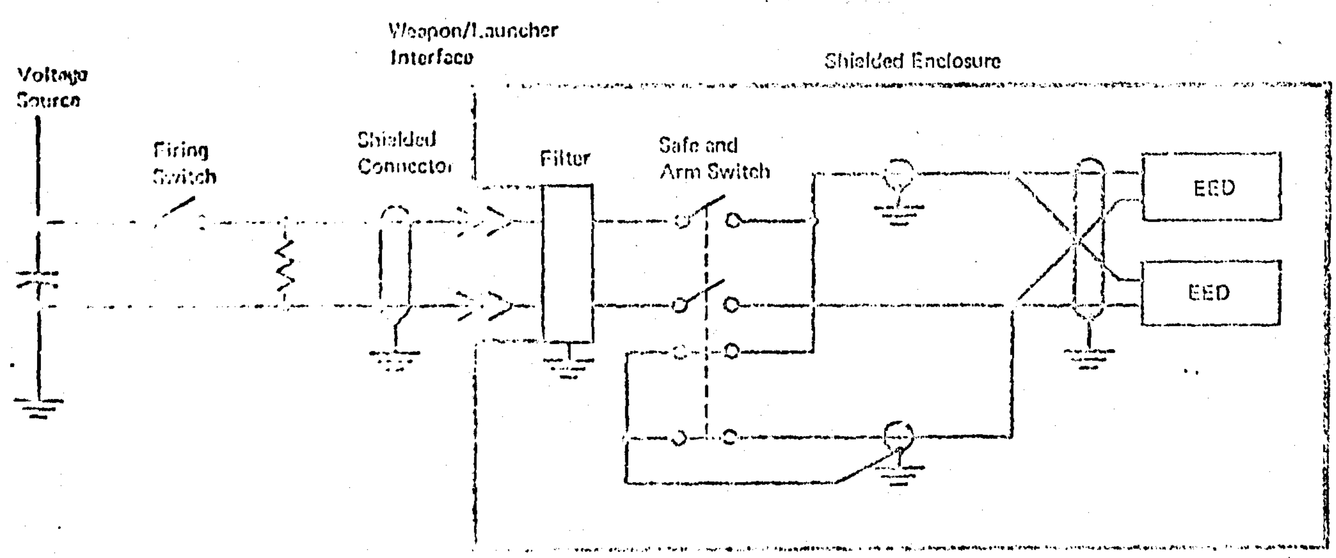


Figure 4-8. Typical Hot Bridgewire Firing Circuit and Safe and Arm Device

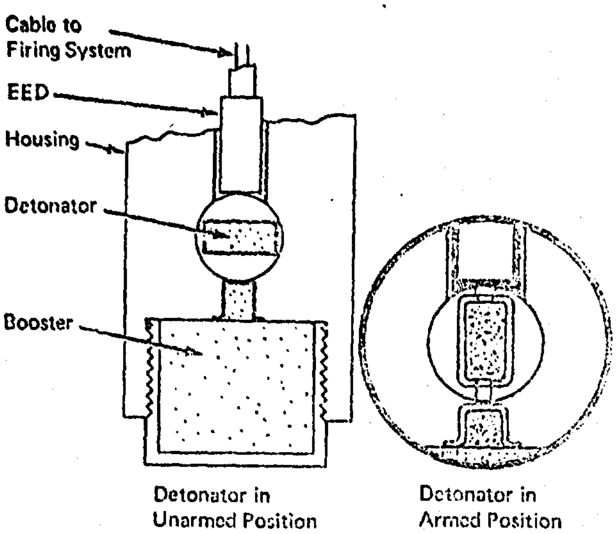


Figure 4-9. Mechanical Safe and Arm Device

Figure 4-10 shows a typical aircraft weapon firing system. As can be seen, the cables attached to the weapon can be quite extensive as they thread through the aircraft. The cables run from the pilot's control console (1) through the fuselage, adjacent to radio and radar equipment (2), into a multi-conductor cable bundle (3), through the wing panel in a cable bundle (4), through the pylon and launcher (5) then to the weapon igniter (6). The cable can have a length of about 25 feet and can be a very effective antenna in an electromagnetic field.

Figure 4-11 shows an air launched weapon in which the connection from the aircraft firing system to the weapon is made through button contacts. These button contacts make the weapon particularly susceptible to HERO during the handling and loading procedures because personnel can touch the contacts and conduct electromagnetic energy directly into the EED. This method of connecting the aircraft firing system to the weapon is not recommended. The system should be designed in such a way as to prevent personnel or tools from touching the conductors that lead into the weapon.

Figure 4-12 shows an air launched weapon partially loaded into its launcher. This weapon is connected electrically to the aircraft firing system by contact rings. These rings are exposed during handling and loading, thus electromagnetic energy can be coupled into the weapon making it susceptible. To help reduce the hazard, a removable shielding band, as shown in the figure, was designed to cover the exposed contacts. This is not a completely satisfactory solution since the bands are not an integral part of the weapon. Also the weapon requires elaborate handling and loading procedures since the bands are removed during loading and the weapon can be unloaded without them, leaving it susceptible. Elaborate handling and loading procedures should not be relied upon to solve the HERO problem because failure to implement them will create a HERO problem.

Figure 4-13 shows a weapon/launcher interface. In the illustration, the umbilical cable is being connected before the weapon is racked to the launcher. This can be a hazardous situation because in an electromagnetic environment, the launcher and the weapon can be at a different rf potential. This difference in potential can cause a flow of rf current in the weapon and greatly increases the possibility of generating an arc as the umbilical is being connected. It may not always be obvious that a high potential difference can exist between aircraft and deck. However, near a vertical whip antenna radiating in the 2 to 32 megahertz range, a potential difference of 200 to 300 volts can exist between aircraft and deck even if conductive tie-downs are used. After the weapon has been secured to the launcher, the rf potentials on the launcher and the weapon are the same or nearly the same, and the possibility of large rf currents and arcs is greatly reduced.

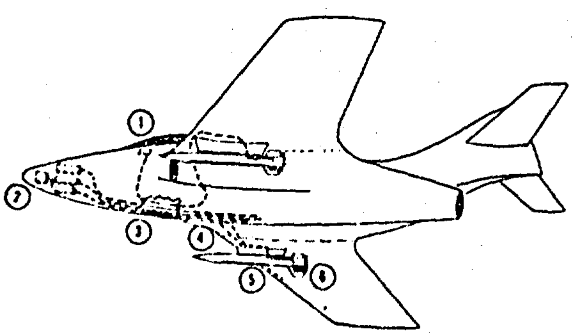


Figure 4-10. Typical Aircraft Weapon Firing System

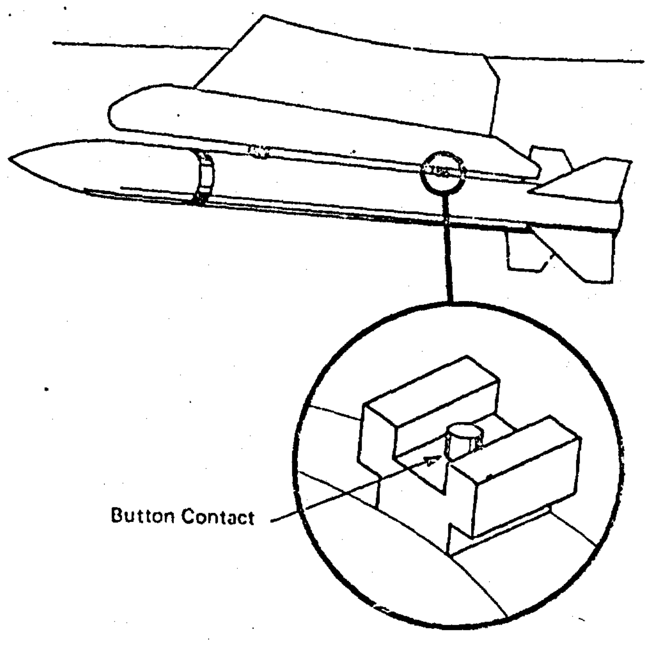


Figure 4-11. Air Launched Weapon

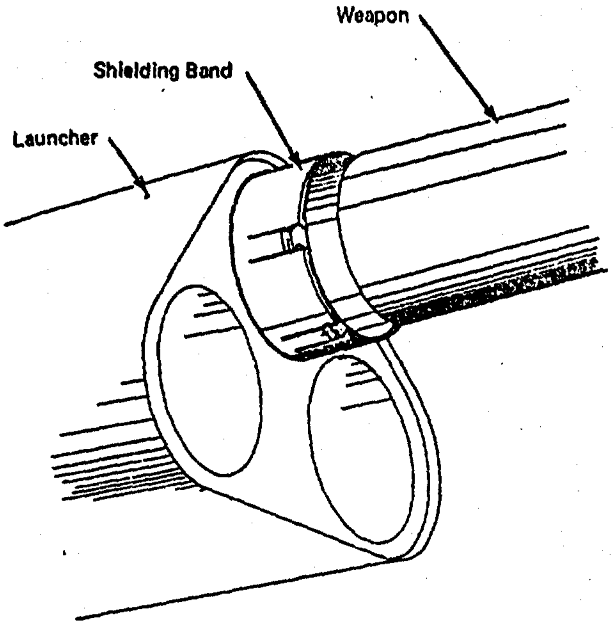


Figure 4-12. Air Launched Weapon Partially Loaded into its Launcher

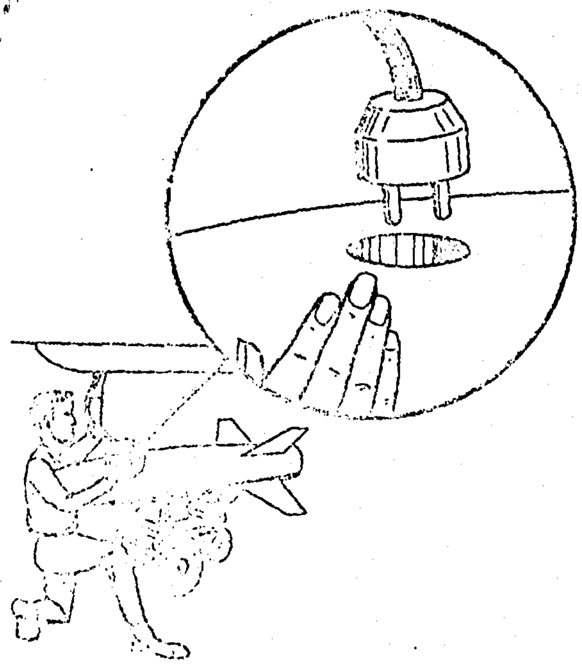


Figure 4-13. Weapon/Launcher Interface

Therefore, the weapon should be designed so that it must be racked before the umbilical cables can be connected. This is illustrated in Figure 4-14. The umbilical cable should be as short as practicable and the cable and its connectors should be completely shielded with the shields properly bonded around the periphery of the shield. The connector should be designed and installed with the male portion on the launcher and the female portion on the weapon. The contacts should be recessed and designed in such a way that the shield mates before the connector pins mate.

Figure 4-15 shows a test set being used to test an ordnance station on an aircraft. This can be a hazardous operation because the test set and external cables can couple energy into the ordnance firing system of the aircraft. This energy can be conducted to ordnance items already loaded. The design of the test equipment and its cabling must be given the same consideration as the design of the weapon itself if a HERO problem is to be prevented. Also, should electromagnetic energy enter the test equipment, it may give false indications. Therefore, the cable and connectors must be properly shielded with the shield bonded to the weapon and to the test equipment to preserve the integrity of the weapon enclosure.

Figure 4-16 shows a typical surface launched weapon with its launcher and control cables. The cable runs from the fire control panel (1) in an armored multiconductor missile control and monitor

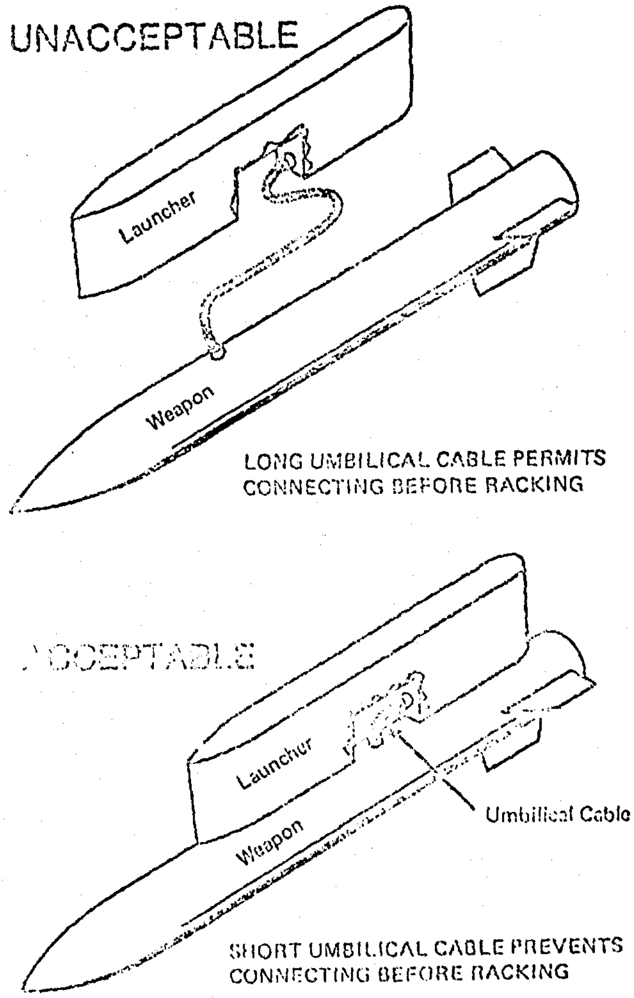


Figure 4-14. Weapon/Launcher Interface and Umbilical Mating

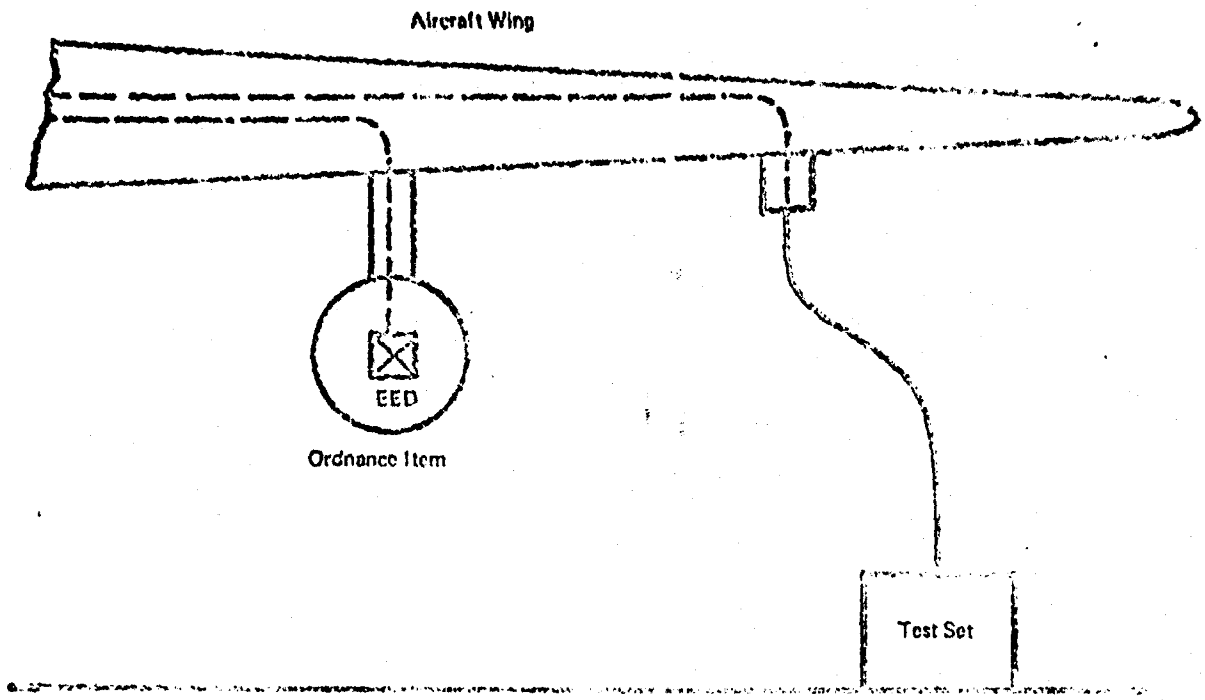


Figure 4-15. Unacceptable Use of Test Set

cable bundle (2), through transfer panels (3) to a slip ring assembly in the launcher pedestal (4), and emerges from the launcher to contact firing shoes of the missile (5). The total length is approximately 90 feet. Because the fire control, monitoring equipment, and cabling are almost entirely enclosed within the ships structure, they are protected to some extent. The weapon launcher and the umbilical cable, on the other hand, are exposed to the electromagnetic environment. Here again, the weapon and the umbilical cable should be properly shielded.

Figure 4-17 shows a surface launched weapon with umbilical cables connected to the weapon and access doors open. The two long umbilical cables create a potential hazard because the two cables can form a loop antenna or the long cables can act as very effective antennas. The number of umbilical cables should be kept to a minimum and the cables should always be as short as possible. The use of access doors or ports may create a hazardous condition because electromagnetic energy can be coupled through them to the firing circuit. When it is

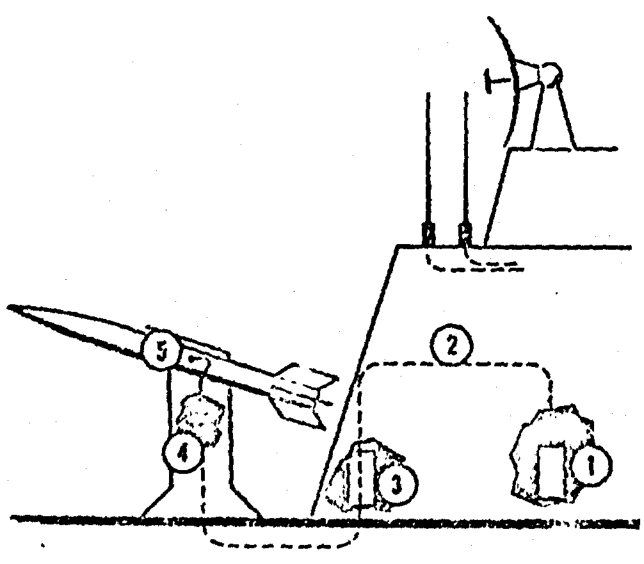


Figure 4-16. Typical Surface Launched Weapon System

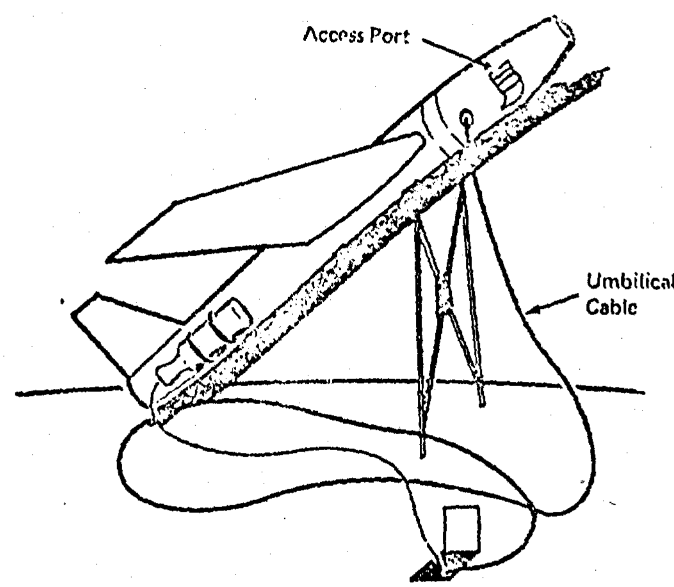


Figure 4-17. Surface Launched Weapon

necessary to have an access door, all of the cables of the firing system that are exposed when the door is open must be shielded. Access doors should be kept to a minimum.

The ability to shield effectively can be greatly impaired while the weapon is being prepared for launch: cables are being handled, connectors are being mated, and access ports on the weapon may be open. Personnel operating, handling, and loading equipment may contribute to the coupling of rf energy into the weapon. When personnel or equipment make contact with any part of the weapon, a situation of rf energy transfer may develop that was not considered in the design of the weapon.

Figure 4-18 shows a weapon being lowered through the hatch of a ship by a crane. The handling crane, acting as a receiving antenna, conducts electromagnetic energy to the weapon and its shipping container. If the weapon is transferred to the ship in a partially assembled or susceptible condition or if there is exposed wiring, the shipping crate should be made of sheet metal and should completely enclose the weapon in such a way as to provide a shield during storage and handling. In some cases, such as in underwater launched weapons, the weapon is transferred to the ship or submarine in an all-up condition and without the container. Care must be taken by the designer to assure that the weapon is safe during this operation.

Figure 4-19 shows the loading of an exploder mechanism in a weapon. There is a specific hazard to personnel during this operation. Ordnance should be designed in such a way that this type of operation can be performed in an area free of electromagnetic energy. If loading an exploder mechanism or performing maintenance operations in the electromagnetic environment is required, the exploder should be completely shielded. The cables and connectors should be designed in such a way as to preclude arcing and the entry of electromagnetic energy.

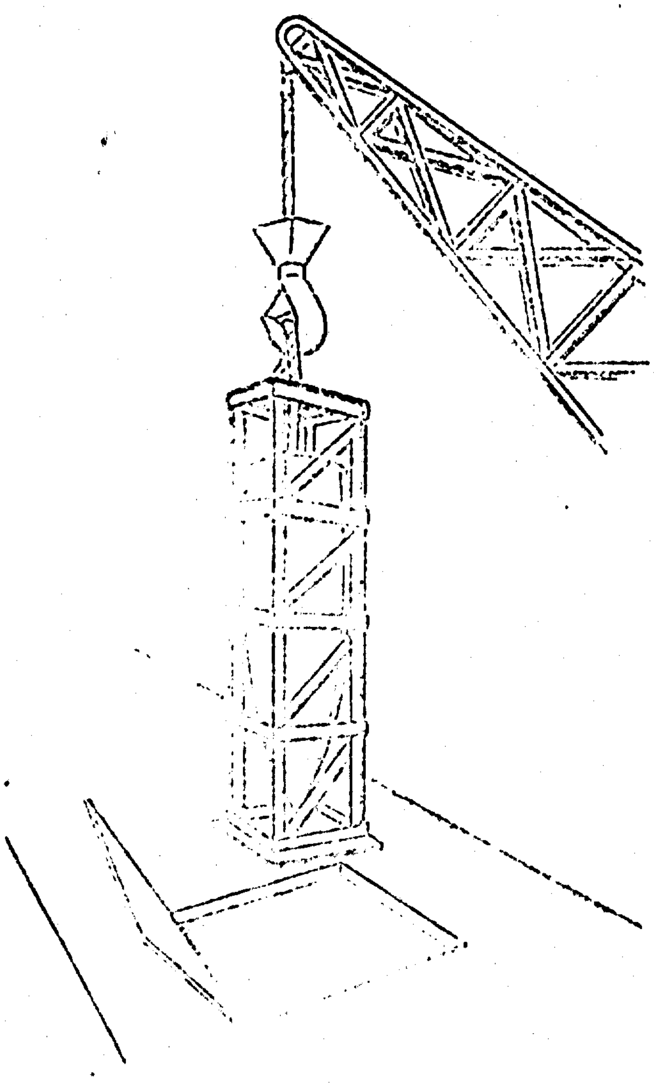


Figure 4-18. Weapon Being Lowered Through Ship's Hatch

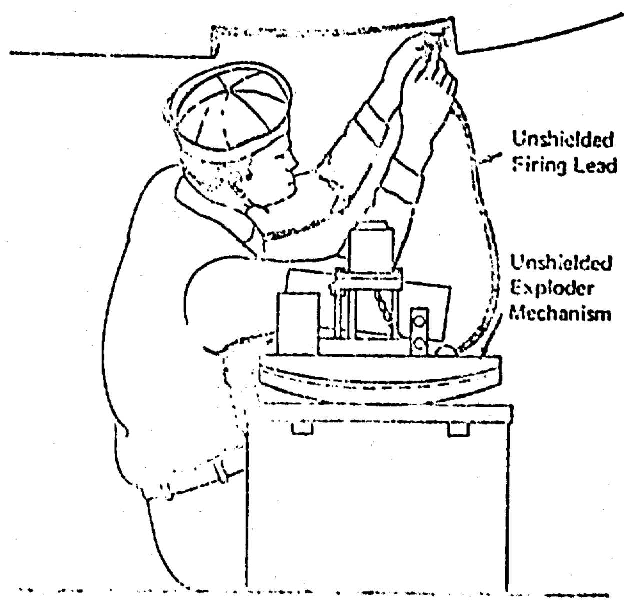


Figure 4-19. Loading of an Exploder Mechanism in a Weapon

Chapter V.
SHIELDING

5.0 GENERAL

The only practical approach for solving the HERO problem is to provide a complete shield for all electroexplosive devices. If it were not for the many mechanical and electrical interfaces required in ordnance systems, the shielding problem would be reduced to choosing a proper shield material and applying the simple box concept described in Chapter I. However, since each interface degrades the shield, the selection and implementation of techniques to provide continuity at these interfaces becomes important. Figures 5-1 and 5-2 illustrate some of the interfaces that can occur.

An electromagnetic shield may be created by the use of any barrier between two regions such that the amount of electromagnetic energy entering one region from the other is reduced. There are a number of types of barriers such as solid metal covers, screened openings, flexible mesh, and honeycomb panels. A weapon may contain many of these barriers in the form of the weapon skin, metal boxes for the igniters, conduits for firing circuits, etc. These can be used to provide some of the shielding required to protect the weapon. The weapon developer should recognize and take advantage of all barriers that the weapon offers.

The effectiveness provided by a shield is defined as the total attenuation of the electromagnetic energy as it attempts to pass through the shield. This includes both reflection and absorption. Most metals thick enough to support their own weight will provide many dB's of attenuation. Thus, the metallic skin of ordnance, when it is continuous, will provide an effective shield.

5.1 SHIELDING THEORY

The shielding action of a metallic barrier can be analyzed by either field theory or circuit theory. In field theory the shield is considered to partially reflect the electromagnetic energy and partially absorb it. The part that is absorbed is attenuated in passing through the shield. In circuit theory, current from the interfacing source is considered to induce a current in the shield such that the external fields due to both of these currents are out of phase and tend to cancel. Field theory will be used in the discussion that follows.

The shielding effectiveness of a shield can be computed by considering reflection and absorption losses as separately contributing factors. It can be written as

$$S = R + A + B,$$

where

S = shielding effectiveness in dB,

R = reflection loss in dB,

A = absorption loss in dB, and

B = internal reflection loss in dB

The internal reflection loss is usually neglected if the absorption loss is greater than 10 dB. Metal walls thick enough to support their own weight have greater than 10 dB absorption loss. Therefore, the shielding effectiveness is usually written as

$$S = R + A.$$

The equations for losses due to reflection are developed from the transmission line equation for reflection of energy at an impedance mismatch. This equation is given as

$$R = 20 \log \left| \frac{(Z_s + Z_w)^2}{4 Z_s Z_w} \right|,$$

where

Z_s = impedance of shield, and

Z_s = impedance of field.

The impedance of the shield barrier) is given as

$$Z_s = (1 + j)\left[\sqrt{f\mu/2\sigma} \times 3.69 \times 10^{-7}\right] \text{ohm}$$

where

μ = relative permeability referred to free space, and

σ = relative conductivity of metal referred to copper.

The impedance of the field is given as

$$Z_w = E/H.$$

It may be either high or low in nature. A high impedance field is one that has an impedance higher than the intrinsic impedance of the dielectric in which it exists. An electric field, such as that generated by a short stub antenna, is high impedance in nature. A low impedance field is one which has an impedance lower than the intrinsic impedance of the dielectric in which it exists. A magnetic field, such as that generated by a small loop antenna, is considered a low impedance field. In a high impedance field, most of the energy is contained in the electric component whereas in a low impedance field, most of the energy is contained in the magnetic component.

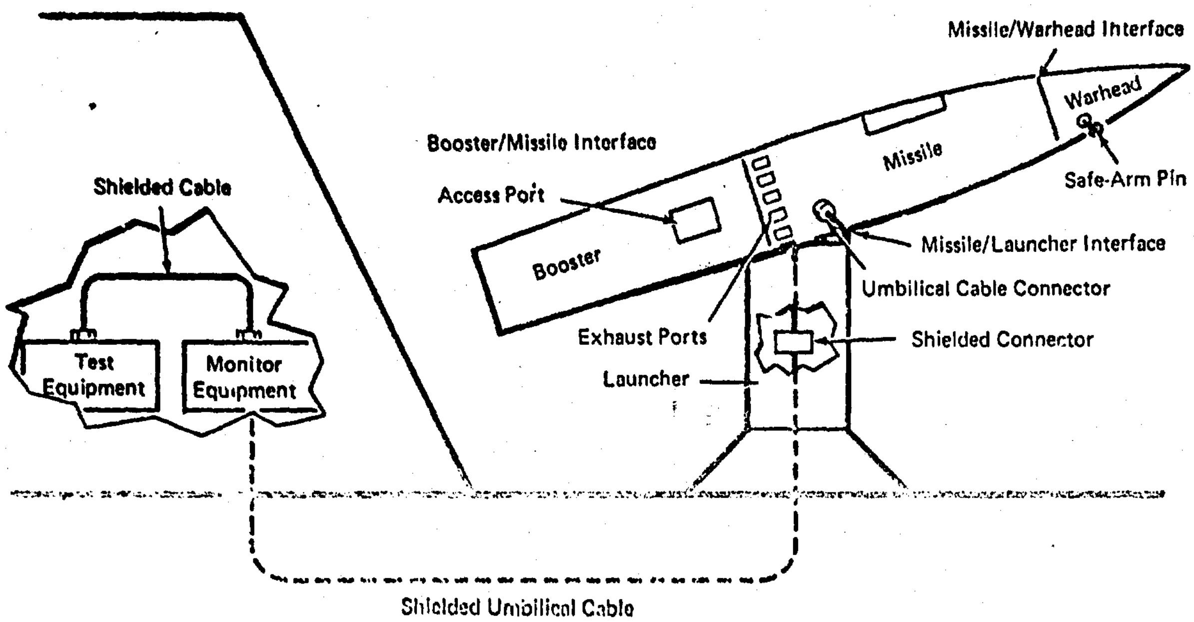


Figure 5-1. Typical Weapon System Shielding Interfaces

The value of Z_W is a function of the type of field and the distance from the source. For a high impedance (or electric) field,

$$Z_W = \frac{1}{C\varepsilon_0} = 377 \text{ ohms if } D >> \lambda, \text{ or}$$

$$= -\frac{j}{\omega\varepsilon_0 D} \text{ if } D << \lambda,$$

where

C = velocity of light,

ε_0 = permittivity of free space,

ω = $2\pi f$, and

D = distance from source in inches.

For a low impedance (or magnetic) field,

$$Z_W = C\mu_0 = 377 \text{ ohm if } D >> \lambda$$

$$= j\omega\mu_0 D \text{ if } D << \lambda,$$

where

μ_0 = permeability of free space

Thus, in the near field the attenuation due to reflection has to be computed differently for the high impedance and the low impedance fields. If the values for Z_W and Z_H are substituted into the preceding equation, we have in the near field (to distances from the antenna of approximately $\lambda/2\pi$) the following equations for reflection loss:

1. High impedance (or electric) fields,

$$R_e = 354 + 10 \log \frac{\sigma}{f^3 \mu D^2} \text{ dB},$$

2. Low impedance (or magnetic) fields,

$$R_h = 20 \log \left[\frac{0.462}{D\sqrt{f\sigma/\mu}} + 0.136\, D \sqrt{f\sigma/\mu} + 0.354 \right] \text{ dB}.$$

In the far field both high and low impedance fields approach that of a plane wave and reflection loss is given as

$$R_p = 168 + 10 \log \sigma/f\mu.$$

The equation for absorption loss can be derived from the propagation constant of the shield material. The propagation constant is given as

$$\gamma = \alpha + j\beta,$$

where

γ = propagation constant,

α = attenuation constant, and

β = phase constant.

For an imperfect conductor the propagation constant can be written as

$$\gamma = (1+j)\, 15.13 \sqrt{f\sigma\mu} \quad \text{dB}.$$

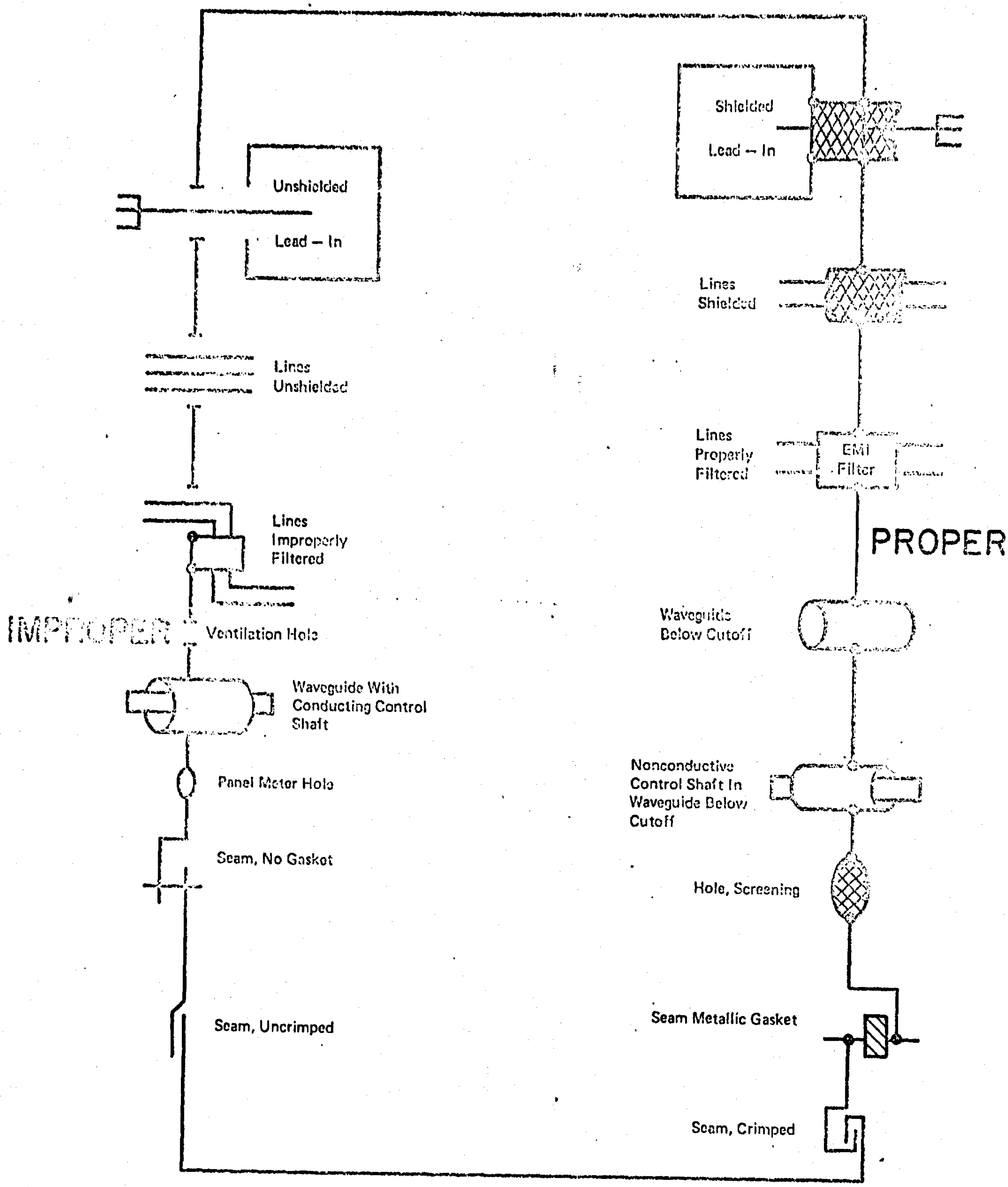


Figure 5-2. Typical Shielded Compartment Discontinuities—Proper and Improper

The attenuation of the wave in passing through the shield once is then

$$A = \alpha t \text{ nepers},$$

$$\text{or } A = 8.686\alpha t \text{ dB},$$

where t is the thickness of the shield in meters.

For t in mils (.001 inch),

$$A = 3.34 \times 10^{-3}\ t\sqrt{f\sigma\mu} \quad \text{dB.}$$

5.2 DETERMINATION OF REFLECTION AND ABSORPTION LOSS

A close approximation for the solution of the reflection and absorption loss equations can be made by using the nomographs of Figures 5-3, 5-4, 5-5, and 5-6.

The product $\sigma\mu$ and the ratio σ/μ needed to solve these equations are given in Table 5-1 or they can be computed using the values of σ and μ obtained from other tables. The value of μ should be the initial permeability.

The reflection loss is a function of the distance from the source to the shield and of the type of wave for distances less than $\lambda/2\pi$. For distances greater than $\lambda/2\pi$ both high and low impedance fields are the same. Here the nomograph for a plane wave is used. In the nomograph for absorption loss, Figure 5-6, the absorption loss per mil is given since absorption loss is proportional to the thickness of the material.

To compute the reflection losses for a plane wave use the equation

$$R_p = 168 + 10 \log \sigma/f\mu \quad \text{dB,}$$

or the nomograph of Figure 5-3. To determine the reflection loss:

1. Locate the ratio σ/μ for the material on the σ/μ scale

2. Place a straightedge between this point and the desired point on the frequency scale

3. Read the reflection loss on the R_p scale.

To compute the reflection losses for distances less than $\lambda/2\pi$, the type of wave must be determined first. If the wave is a low impedance (or magnetic) field use the equation

$$R_h = 20 \log \left[\frac{0.462}{D} \frac{1}{\sqrt{f\sigma/\mu}} + 0.136\, D \sqrt{f\sigma/\mu} + 0.354 \right] \text{dB.}$$

If the wave is a high impedance (or electric) field use the equation

$$R_e = 354 + 10 \log \frac{\sigma}{f^3 \mu D^2} \quad \text{dB.}$$

These equations can be approximated by using the nomographs of Figures 5-4 and 5-5. To find reflection loss use the figures as follows:

1. Determine the distance from the source to the shield and locate this on the D scale.

2. Place a straightedge between this point and the desired point on the frequency scale.

3. Locate the point on the transfer scale where the straightedge crosses it.

4. Place the straightedge between this point and a point on the scale corresponding to the ratio σ/μ of the material.

5. Read the reflection loss on the R_n or R_e scale as appropriate.

The absorption loss can be computed by using the equation

$$A = 3.34 \times 10^{-3}\ t\sqrt{f\sigma\mu} \quad \text{dB,}$$

or by using the nomograph of Figure 5-6. This nomograph can be used to determine either the absorption loss of an existing shield or to determine the material and thickness of the material needed to provide a predetermined absorption loss. In the first case, the type of material used for the shield, for example the weapon case, must be determined and the product $\sigma\mu$ obtained. To find the absorption loss:

1. Locate the product $\sigma\mu$ on the $\sigma\mu$ scale.

2. Place a straightedge between this point and the desired point on the frequency scale.

3. Read the absorption loss per mil on the A/t scale.

4. Multiply this value by the thickness of the shield material to get the total absorption loss.

In the second case, various materials can be investigated to determine the thickness of each that is needed to provide the desired protection. The material to be used can then be selected based on the thickness required plus other engineering considerations. In order to make this determination, the following must be known or computed: the total shielding effectiveness, the reflection loss (which is independent of the thickness), and the absorption loss. The absorption loss is the difference between the shielding effectiveness and the reflection loss.

$$R_p = 168 + 10 \log \frac{\sigma}{f\mu}$$

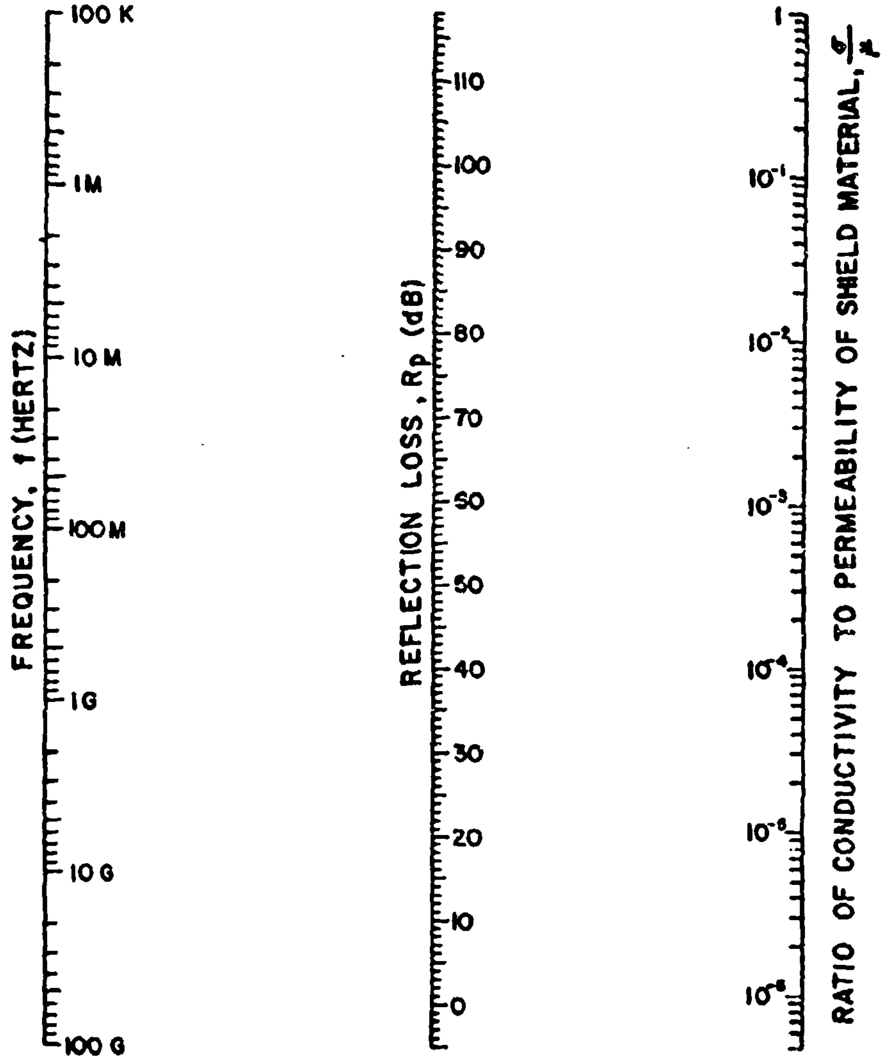


Figure 5-3. Plane Wave Reflection Loss (R_p)

$$R_h = 20 \log \left[\frac{0.462}{D\sqrt{f\,\sigma/\mu}} + 0.136\, D\sqrt{f\,\sigma/\mu} + 0.354 \right]$$

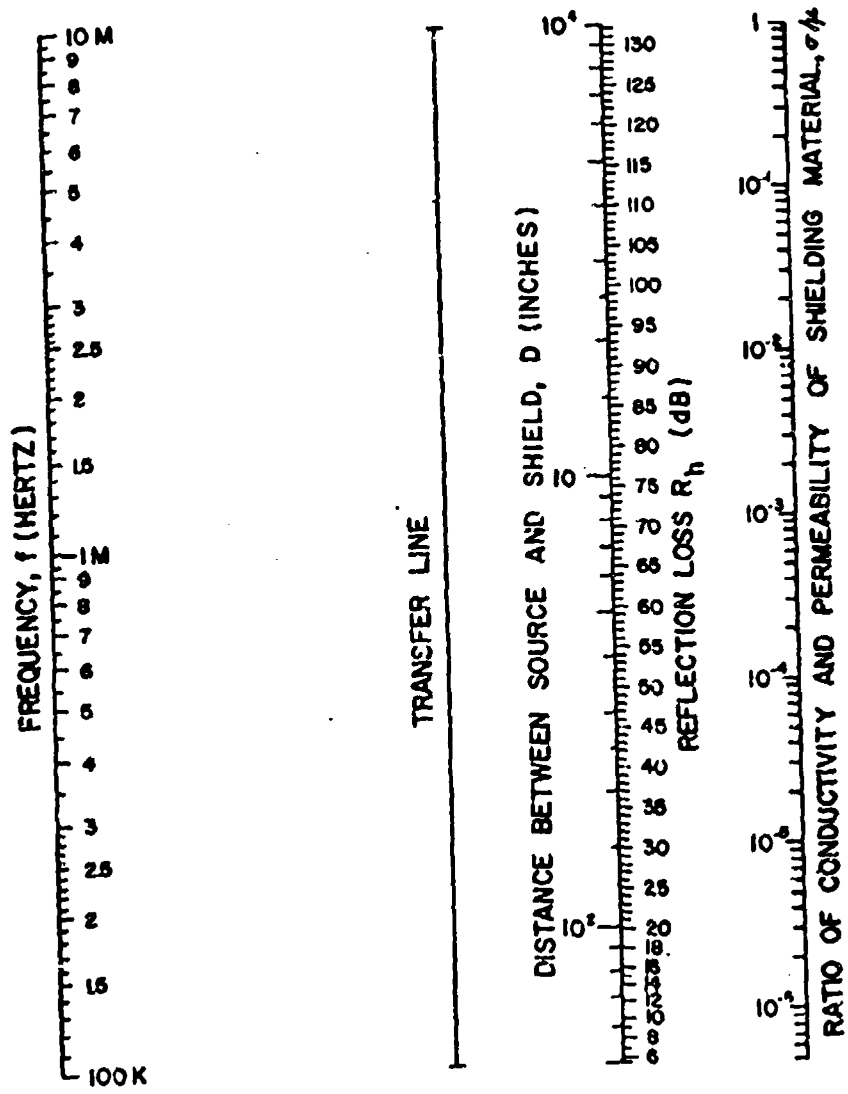


Figure 5-4. Magnetic Field Reflection Loss (R_h)

$$R_e = 354 + 10 \log \frac{\sigma}{f^3 \mu D^2}$$

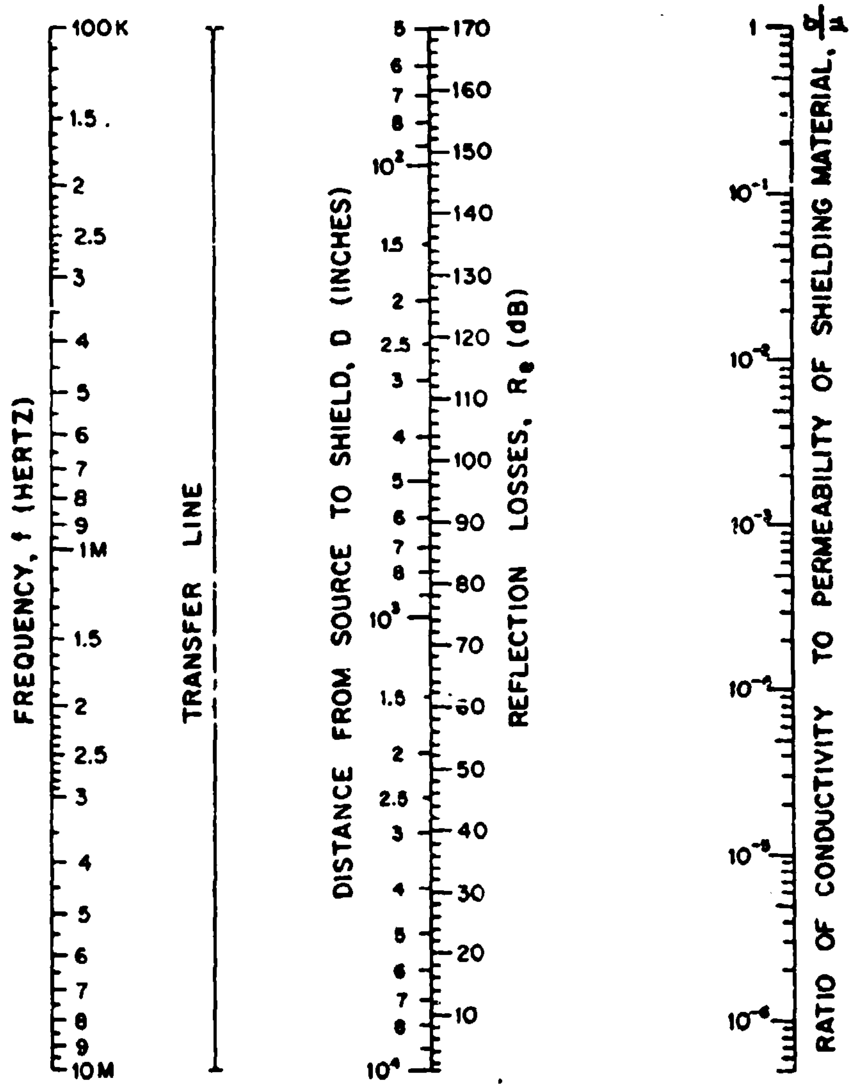


FIGURE 5-5 ELECTRIC FIELD REFLECTION LOSS (R_e)

Figure 5-5. Electric Field Reflection Loss (R_e)

$$A/t = 3.34 \times 10^{-3}\sqrt{f\sigma\mu}$$

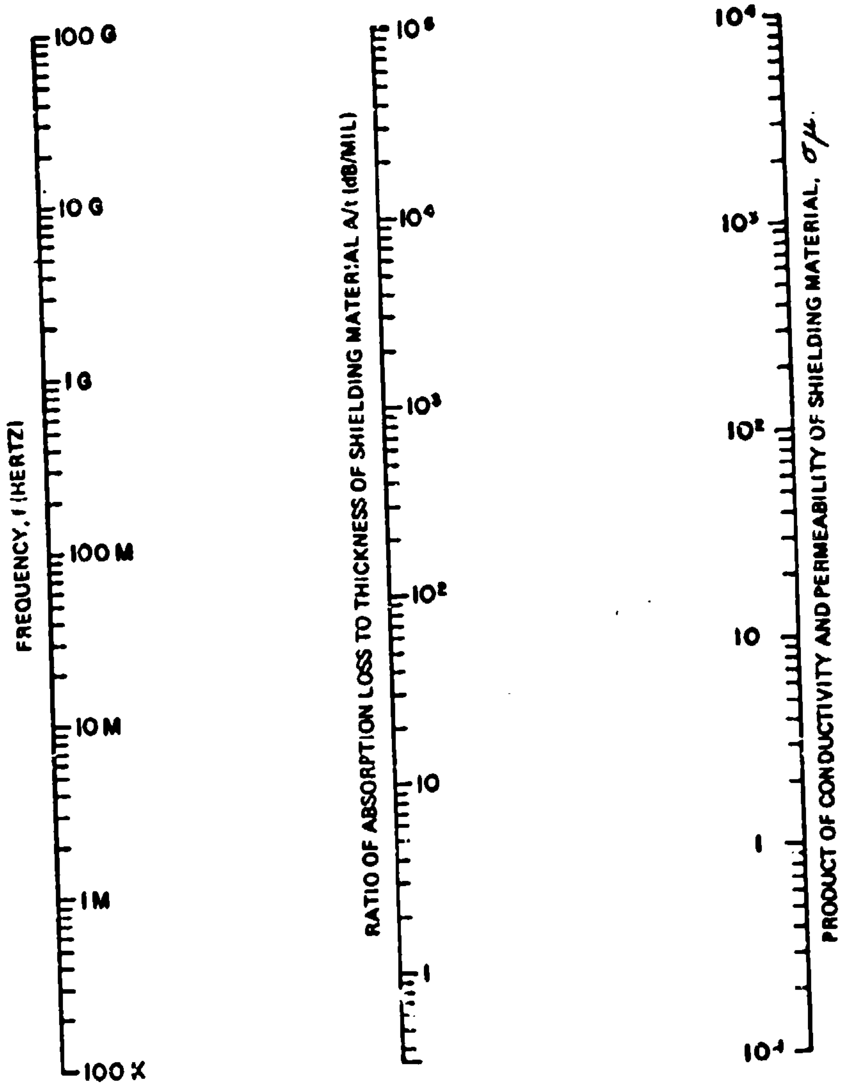


Figure 5-6. Absorption Loss (A/t)

Table 5-1. Characteristics of Various Materials Used for Shields

Name of Material	Remarks	Resistivity (ohm-cm x 10^{-6}) at 20°C	Relative Conductivity Referred to Copper (σ)	Initial Permeability Relative to Free Space (μ)	$\sigma\mu$	$\frac{\sigma}{\mu}$
Low Permeability Materials						
Silver		1.59	1.1	1	1.1	1.1
Copper, Annealed		1.7241	1.0	1	1.0	1.0
Gold		2.44	.71	1	7.1×10^{-1}	7.1×10^{-1}
Aluminum		2.824	.61	1	6.1×10^{-1}	6.1×10^{-1}
Brass	66% Cu, 34% Zn	3.9	.44	1	4.4×10^{-1}	4.4×10^{-1}
Beryllium		4.57	.38	1	3.8×10^{-1}	3.8×10^{-1}
Magnesium		4.6	.37	1	3.7×10^{-1}	3.7×10^{-1}
Zinc		5.8	.30	1	3.0×10^{-1}	3.0×10^{-1}
Cadmium		7.6	.23	1	2.3×10^{-1}	2.3×10^{-1}
Phospher Bronze	4% Sn, 0.5% P Bal. Cu	9.4	.18	1	1.8×10^{-1}	1.8×10^{-1}
Tin		11.5	.15	1	1.5×10^{-1}	1.5×10^{-1}
Lead		22.0	.078	1	7.8×10^{-2}	7.8×10^{-2}
Steel, Stainless	0.1% C, 18% Cr, 8% Ni, Bal. Iron (1)	90.0	.019	1	1.9×10^{-2}	1.9×10^{-2}
Medium Permability Materials						
Nickel	99% Ni Heat Treatment 1000°C (2)	7	.25	110	28	2.3×10^{-3}
Steel, Mild	0.2% C Heat Treatment 950°C (2)	10	.17	120	20	1.4×10^{-3}
Steel, Cold Rolled	98.5% Fe Heat Treatment 950°C	10	.17	180	31	9.4×10^{-4}
Iron	99.91% Fe Heat Treatment 950°C	10	.17	200	34	8.5×10^{-4}

Table 5-1. Characteristics of Various Materials Used for Shields (continued)

Name of Material	Remarks	Resistivity (ohm-cm x 10^{-6}) at 20°C	Relative Conductivity Referred to Copper (σ)	Initial Permeability Relative to Free Space (μ)	$\sigma\mu$	$\frac{\sigma}{\mu}$
High Permeability Materials						
Iron, Purified	99.95% Fe Heat Treatment 1480°C (H_2) + 880°C (3)	10	.17	5000	8.5×10^2	3.4×10^{-5}
78 Permalloy	78.5% Ni, 21.2% Fe, 0.3% Mn Heat Treatment 1050°C + 600°C (Q) (4)	16	.11	8000	8.8×10^2	1.4×10^{-5}
45 Permalloy	45% Ni, 54.7% Fe, 0.3% Mn Heat Treatment 1050°C	45.0	.038	2500	95	1.5×10^{-5}
Hipernik	50% Ni, 50% Fe Heat Treatment 1200°C (H_2) (3)	50.0	.034	4500	150	7.5×10^{-6}
4-79 Permalloy	79% Ni, 16.7% Fe, 4% Mo, 0.3% Mn Heat Treatment 1100°C plus Quench	55.0	.031	20,000	620	1.5×10^{-6}
Hymu 80	80% Ni, Bal. Iron	58.0	.030	10,000	300	3.0×10^{-6}
Supermalloy	79% Ni, 15.7% Fe, 5% Mo, 0.3% Mn Heat Treatment 1300°C (H_2) plus Quench (3)	60.0	.029	100,000	2.9×10^3	2.9×10^{-7}
Iron, 4% Silicon	96% Fe, 4% Si Heat Treatment 800°C Anneal	60.0	.029	500	14	5.8×10^{-5}
Mu metal	75% Ni, 18% Fe, 2% Cr, 5% Cu Heat Treatment 1175°C (H_2) (3)	62.0	.028	20,000	5.6×10^2	1.4×10^{-6}

(1) Higher permeabilities may be obtained after cold working.
(2) Remainder iron and impurities. Presence of 0.3-0.5% Mn not noted.
(3) (H_2), annealed in atmosphere of pure hydrogen.
(4) (Q), Quenched from indicated temperature.

The data in this table was compiled from the following sources and is being reprinted through the courtesy of and by the permission of the publishers:

Weast, R. C. Ph.D., Handbook of Chemistry and Physics 51st Edition, Chemical Rubber Co., 18901 Cranwood Parkway Cleveland, Ohio 44128

Bozorth, R. M., Ferromagnetism, Van Nostrand Reinhold Co., Div. of Litton Educational Publishers, Inc., 450 W. 33rd St. New York, New York 10001

Reference Data for Radio Engineers, 5th Edition, Howard W. Sams and Co., 4300 W. 22nd St. Indianapolis, Indiana 46268 (The data on Hymu 80 was reprinted by permission from S. R. Hoh, "Evaluation of High-Performance Care Materials (Part 1), "Tele-Tech and Electronic Industries, Vol. IL pp. 86-89, 154-156; Oct. 1953)

To determine the thickness required:

1. Locate the product $\sigma\mu$ on the $\sigma\mu$ scale.

2. Place a straightedge between this point and the desired point on the frequency scale.

3. Read the absorption loss per mil on the A/t scale.

4. Divide the required absorption loss by this value to get the required thickness.

5.3 SELECTION OF SHIELDING MATERIAL

The reflection and absorption losses in a shield are a function of the type of material and depend on the type of field and the distance from the source. The reflection and absorption losses for copper, 1 mil thick and located 100 inches from the source are plotted in Figure 5-7. The plot of losses for other material would be similar. The desirable properties of materials that make effective shields can be determined by studying the equations used for computing these losses and the curves of Figure 5-7. The inherent properties of metals that make them effective shields are conductivity σ and permeability μ. The important physical property is thickness.

In the near field, the high impedance or electric field is the easiest to shield against. As can be seen from Figure 5-7, the reflection losses for the electric field are high at low frequencies and the absorption losses are low. As the frequency increases, reflection losses decrease but absorption losses increase. Both reflection and absorption losses are directly proportional to σ. Absorption losses are directly proportional to μ, and reflection losses are inversely proportional to μ. Since reflection losses do not generate heat in the shielding material, they are more desirable for HERO application than absorption losses, which do generate heat as the energy is attenuated. Therefore a material with high σ, such as brass, copper, or aluminum, is preferred for the shielding material in an electric field. Thickness is not an important consideration.

The most difficult field to shield against is the low impedance (or magnetic) field. As shown in Figure 5-7, both magnetic reflection and absorption losses are low at low frequencies. As the frequency increases both reflection losses and absorption losses increase. At very low frequencies, the first term in the equation for R_h is the dominant factor, hence, reflection losses are directly proportional to μ. Also, since absorption losses are important, thickness is an important factor. Thus, thick slabs of magnetic (high μ) material are required to shield magnetic fields at very low frequencies. Materials that make excellent shields for electric fields are of little use in low frequency magnetic fields.

As the frequency of the magnetic field increases, the dominant factor in the equation for R_h is the second term and thus at higher frequencies the reflection losses are directly proportional to σ, and inversely proportional to μ. The absorption losses are directly proportional to σ. Here materials with high σ, such as those used for electric fields, are suitable.

In the far field, shielding is obtained by using both reflection and absorption losses. The reflection losses for the plane wave decrease and absorption losses increase as the frequency increases. These relationships are shown in Figure 5-7.

The absorption and reflection losses are directly proportional to σ as in the case of the electric field. Therefore, materials with high σ are suitable for shielding.

The preceding can be summarized as follows:

1. For magnetic fields, only magnetic material can be used for shields at low frequencies.

2. For electric fields, materials with high σ are adequate for shields.

3. For plane waves, materials with high σ are adequate for shields (both magnetic and electric fields).

4. For any given material, a greater shield thickness is required for magnetic fields than for electric fields.

5. For any given material, a greater shield thickness is required for low frequencies than for high frequencies.

6. For high frequencies, absorption losses become important. Therefore, to maintain the shielding effectiveness, all openings must be closed.

5.4 WOVEN AND PERFORATED MATERIALS

There are many applications where the shield cannot be made of a solid material but must be made of a transparent or perforated material. Examples of these are covers for meters and gauges, which must be read through the shield, and planned holes for ventilation or circuit adjustment. Woven materials such as wire mesh can be used over instruments and perforated materials or honeycomb panels can be used for ventilation or circuit adjustment.

The effectiveness of any shield may be severely degraded by poor ohmic contact between adjacent parts. For this reason, the effectiveness of woven materials is likely to be more dependent on the contact resistance at the junctions of wires in the weave, than on the resistivity and

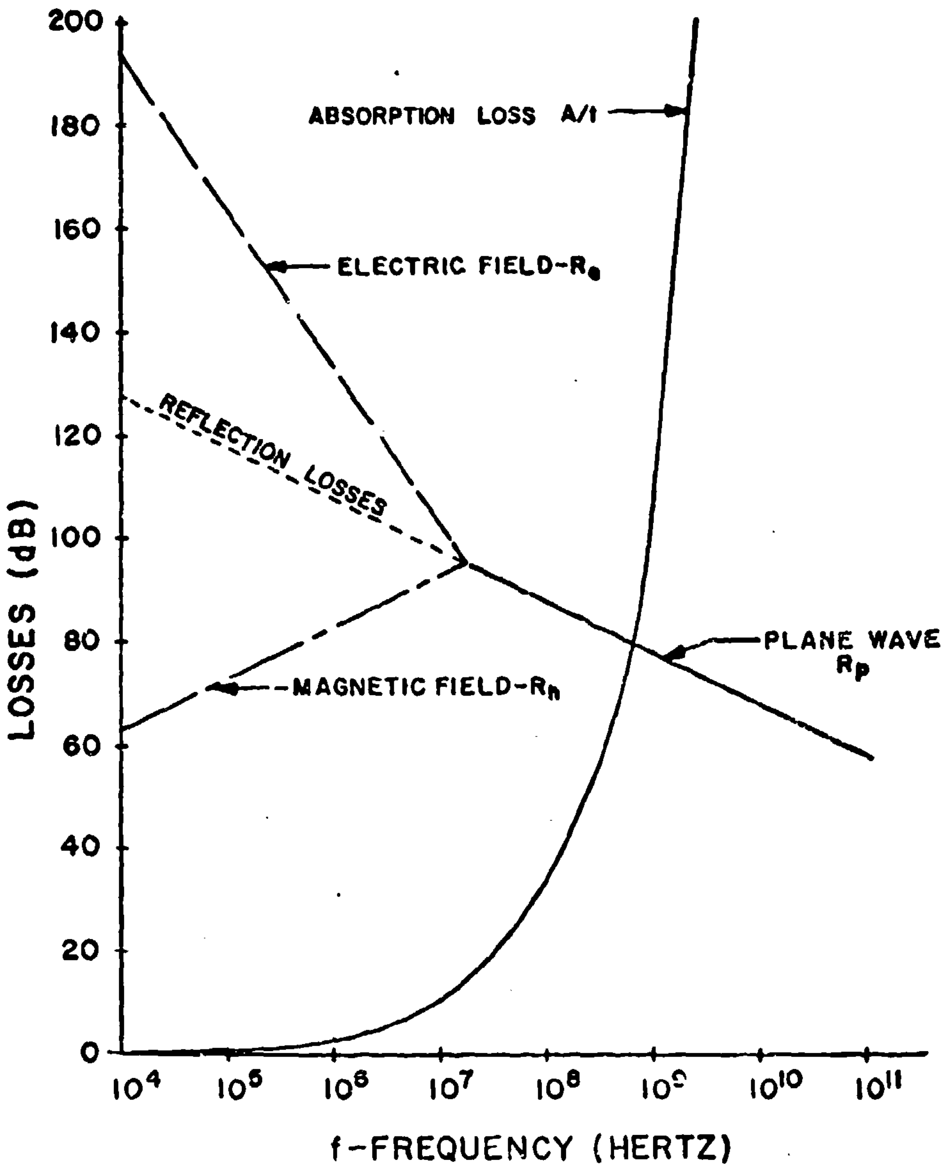


Figure 5-7. Reflection and Absorption Losses for a Solid Copper Shield 1 Mil Thick and Located 100 Inches From the Source

permeability of the wires themselves. An extreme example would be the case where an unknowing painter happens by and does a thorough paint job on a loosely woven screen. The paint tends to insulate each wire from all the others, markedly reducing the effectiveness of the screen for shielding purposes. A preferred type of wire weave has the intersections of the wires either soldered or welded, and even better is a solid sheet of metal perforated with the required size and number of holes.

With perforated sheets, the fewer and smaller the holes, the better the shielding effectiveness. With woven wires, the larger the wire size and the greater the density of wires per square inch, the better. Tables 5-2 and 5-3 show the attenuation of two common types of woven wire mesh for magnetic fields and radiated fields respectively.

Honeycomb panels are formed by a series of cylindrical, rectangular, or hexagonal tubular openings. When properly designed, they act as a high pass filter with a cutoff frequency. The cutoff frequency is the lowest frequency at which propagation occurs without attenuation. The depth of the aperture determines the amount of attenuation realized and the diameter of individual openings determines the cutoff frequency.

The cutoff frequency of the hole can be determined by use of the following expressions:

$$F_c = \frac{5900}{b} \text{ for a rectangular waveguide}$$

and

$$F_c = \frac{6920}{d} \text{ for a circular waveguide,}$$

where

F_c = cutoff frequency in megahertz,

b = longest transverse dimension of waveguide in inches, and

d = diameter of waveguide in inches.

Assuming $F_c \geq 10F$ (when F is the frequency in megahertz per second), the attenuation of circular and rectangular waveguides respectively of length ℓ, may be approximated within a two percent error by the following formulas:

$$A = 32\frac{\ell}{d} \text{ for circular waveguides, and}$$

$$A = 27.3\frac{\ell}{b} \text{ for rectangular waveguides.}$$

These equations are valid for air-filled waveguides with a length-to-width or length-to-diameter ratio of 3 or greater.

The shielding effectiveness of a honeycomb panel constructed of steel with 1/8-inch hexagonal openings, 1/2-inch long is given in Table 5-4.

5.5 CONDUITS

Conduits made of either solid or woven strands of metal may be used to shield the firing or system cables of a weapon from the electromagnetic environment. The shielding effectiveness of solid conduit can be considered, for all HERO purposes, the same as that of a solid sheet of the material of the same thickness. The most common material used for shielding is the woven wire conduit. Its shielding effectiveness can be determined by tests conducted in accordance with MIL-STD-1377 (Navy).

Degradation of the shielding effectiveness in conduit is often the result of discontinuities in the shield rather than insufficient shielding properties of the conduit material. These discontinuities result from splicing, damage, or most frequently, improper termination of the shield.

Table 5-2. Wire Mesh Cloth: Magnetic Field Attenuation vs. Frequency

Frequency (MHz)	Copper		Galvanized Steel	
	18 x 18 (Wires/in²)	22 x 22 (Wires/in²)	22 x 22 (Wires/in²)	26 x 26 (Wires/in²)
	Attenuation (dB)		Attenuation (dB)	
0.01	59.3	65.4	94.1	100.3
0.03	70.0	76.1	101.3	107.4
0.06	76.7	82.8	104.0	110.1
0.1	81.1	87.2	105.4	111.5
0.3	90.3	96.4	106.7	112.8
0.6	94.7	100.8	107.0	113.1
1	97.0	103.1	107.1	113.2
3	99.8	105.9	107.3	113.4
6	100.6	106.7	107.3	113.4
10	100.8	106.9	107.3	113.4
30	101.2	107.2	107.3	113.4
60 - 10,000	101.2	107.2	107.3	113.4

Table 5-3. Wire Mesh Cloth: Radiated Field Attenuation vs. Frequency

Frequency (MHz)	Copper		Galvanized Steel	
	18 x 18 (Wires/in²)	22 x 22 (Wires/in²)	22 x 22 (Wires/in²)	26 x 26 (Wires/in²)
	Attenuation (dB)		Attenuation (dB)	
0.01	103.6	109.1	137.7	143.9
0.03	104.7	110.2	135.4	141.6
0.06	105.4	110.2	132.1	138.3
0.1	105.4	113.6	129.1	135.3
0.3	105.0	110.5	120.8	127.0
0.6	103.4	108.9	115.1	121.3
1	101.3	106.8	110.8	117.0
3	94.5	100.0	101.4	107.6
6	89.3	94.8	95.4	101.6
10	85.1	90.6	91.0	97.2
30	75.8	81.3	81.4	87.6
60	69.9	75.4	75.4	81.6
100	65.6	71.0	71.0	77.2
300	55.9	61.4	61.4	67.6
600	49.9	55.4	55.4	61.6
1000	45.5	51.0	51.0	57.2
3000	35.9	41.4	41.4	47.6
6000	29.9	35.4	35.4	41.6
10,000	25.5	31.0	31.0	37.2

Table 5-4. Shielding Effectiveness of Hexagonal Honeycomb Made of Steel, with ⅛-Inch Openings, ½-Inch Long

Frequency	Shielding Effectiveness
100 KHz	45 dB
50 MHz	51 dB
100 MHz	57 dB
400 MHz	56 dB
2200 MHz	47 dB

Armored conduit, as used aboard ship, can provide effective shielding at lower frequencies, but at higher frequencies the openings between individual strands can take on slot-antenna characteristics, causing a serious degradation of the shielding effectiveness. If armored conduit is required, all internal wiring should be individually shielded.

5.6 SHIELD DISCONTINUITIES

Shield discontinuities in weapon systems occur at cable shield terminations, construction seams, connectors, and planned openings such as access doors, meter ports and openings for control rods. These discontinuities should be kept to a minimum by proper design practices. Where discontinuities are unavoidable, the integrity of the shield should be maintained by use of filters, wire mesh, or rf gaskets. Waveguide openings designed to operate below cutoff should be used if a shaft has to penetrate the shield. Only nonconductive material should pass through the waveguide opening. A conductive material will act as an antenna and will destroy the shielding effectiveness.

5.7 SHIELD TERMINATIONS

The effectiveness of a cable shield depends upon the proper termination of the shield. Rf currents that are conducted along the shields of cables will be coupled into the system at the point of improper cable termination and reduce the effectiveness of an otherwise adequately shielded weapon. In a properly terminated shield, the entire periphery of the shield is grounded to a low impedance reference, minimizing any rf potentials at the surface of the termination.

Figure 5-8 illustrates cable-shield-to-connector termination and connector-to-bulkhead termination. Figure 5-9 illustrates the method of preserving individual shields when more than one shielded conductor must be routed through a single cable and connector. The shield should never be pulled back, twisted, and then bonded to the connector in a pigtail fashion. No portion of the shield

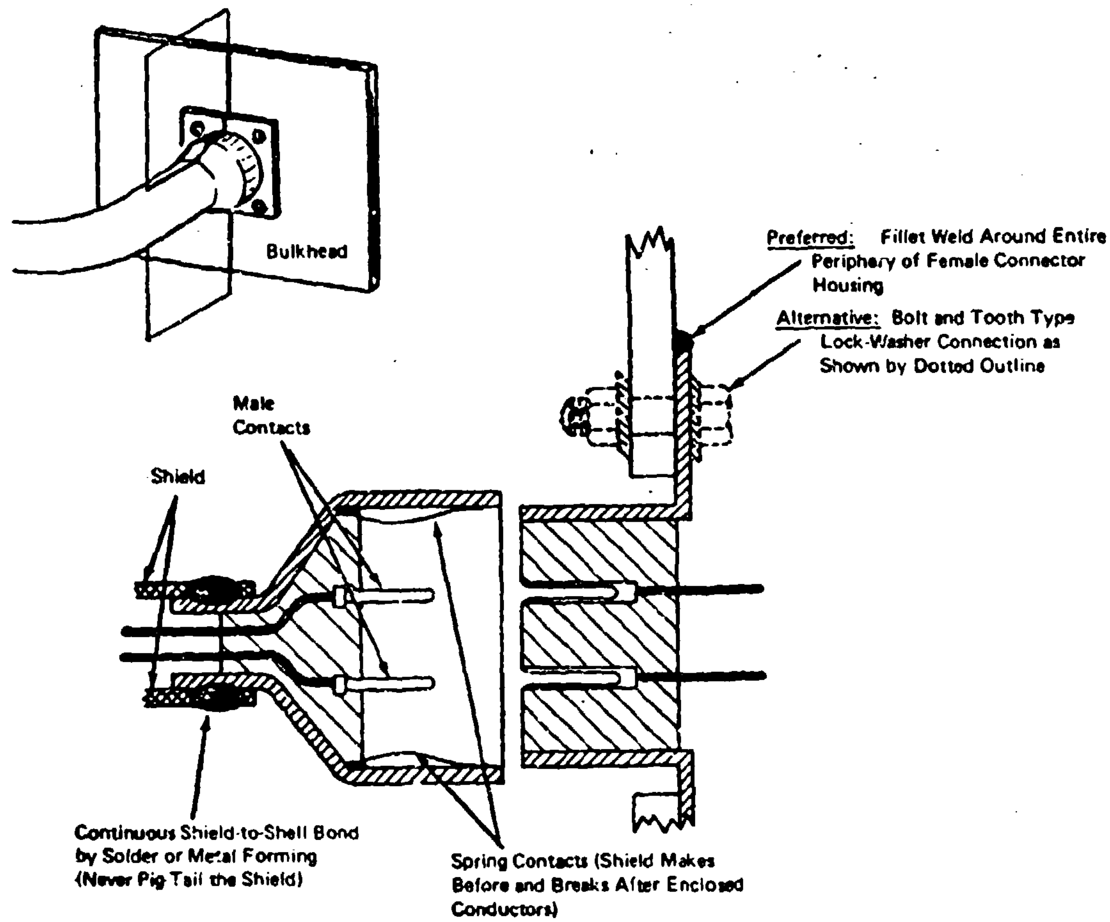


Figure 5-8. Shield Termination For Electrical Connectors

should be broken before it is bonded to the connector shell. Individual shields for conductors that are routed through multi-coaxial connectors should be terminated individually in the manner described above. The shield termination technique illustrated in Figure 5-10 should be used when a shielded cable is routed into a completely shielded enclosure. When cable tension or vibration would discourage such a termination, rigidly supported connectors should be used.

It should be noted that there are situations in which an improper shield can actually increase the hazard to the EED. A fairly common EED configuration is one having unshielded leads. Since there is no provision for completing a shield to the case of the EED, the weapons designer faces a situation in which the effort to provide a shield may create a problem. If a shield is placed over the lead wires and allowed to be ungrounded at the EED, the shield discontinuity will support the generation of high voltages directly at the EED. Consequently the shield would contribute to the hazard. In such situations it is better not to attempt to shield the EED. If the shield must be extended to the EED, then the EED should be specified and purchased with shielded leads installed in the manufacturing process.

5.8 CONNECTORS

Connectors used in firing circuits should preclude the entry of electromagnetic energy. All rf connectors are not designed for this purpose. To be acceptable, the shielding effectiveness of the mated connector should be equal to or better than an equal length of the cable used in the circuit.

In order to prevent electromagnetic energy from entering the circuit at the connector interface the following features should be considered:

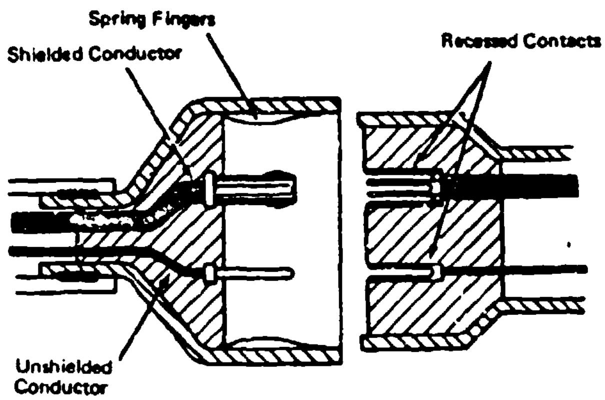


Figure 5-9. Multi-Coaxial Connector Design

1. There should be no breaks in the shield through the connector and cable which would allow electromagnetic energy to "leak" into the firing circuit.

2. The connector should be able to withstand environmental conditions (vibration, high and low temperatures, corrosion, etc.) without degradation of the shielding characteristics of the connector.

3. The connector shield at the interface of the two connector halves must make positive contact before the two power contacts make and must maintain contact until after the power contacts break.

4. The firing system contacts in the connector mating sections should be sufficiently isolated to preclude the possibility of field personnel accidentally touching the socket contacts, either with their fingers or with the mating connector shell, while the connectors are unmated.

5.9 BONDING

Electrical bonding is the union of two metallic surfaces to provide a low impedance connection. Good bonding is necessary to produce a seam that is electromagnetically tight. If the impedance of the seam is higher than that of the metals being joined, rf voltages can develop across the seam from skin currents, permitting electromagnetic energy to enter the shielded enclosure. Generally, the impedance of the bond becomes more important as the frequency increases, because skin effect can cause the impedance to increase as the frequency increases.

Mating surfaces of metallic members within a weapon should be bonded together by welding, brazing, sweating, swaging, soldering, or metal forming. Semipermanent bonds, such as those provided by bolts or rivets, are acceptable when good electrical contact exists between bare metal surfaces. Star or lock washers may be used with threaded devices to ensure continued electrical contact and tightness. Star washers are very effective in cutting through nonconductive coatings such as those caused by corrosion. Joints that are press fitted or joined by self-tapping or sheet metal screws cannot be relied upon to provide a low-impedance bond at high frequencies. Riveted joints on 3/4-inch centers are acceptable if the rivet holes are bare. Direct bonds must always be made through continuous contact between bare, conductively finished metals.

Several configurations which form seams between two metallic members within a weapons system are shown in Figure 5-11. The preferred seam is a continuous weld around the periphery of the mating surfaces. The type of weld is not critical, provided the weld is continuous. Spot welding can also be used provided care is exercised to prevent gaps in the mating surfaces between the spot welds. The spot weld joints should be less than two inches apart. An acceptable alternative technique is the crimp seam pictured in Figure 5-12. In a crimp seam, all non-conductive materials must be removed from the mating surfaces before the surfaces are crimped. The crimping must then be performed under sufficient pressure to insure positive contact between all mating surfaces. Table 5-5 summarizes, in order of preference, techniques for producing permanent or semipermanent seams.

To insure adequate and properly implemented techniques, the following recommendations should be observed:

1. All mating surfaces must be cleaned before bonding. The area cleaned should be slightly larger than the area to be bonded.

2. All protective coatings having a conductivity less than that of the metals being bonded must be removed from the contact areas of the two mating surfaces before the bond connection is made. (The conductivity of coating such as anodizing materials should be verified with the manufacturer whenever it is questionable).

3. Mating surfaces should be bonded immediately after protective coatings are removed to avoid oxidation.

4. The nonreplaceable portion of a bonded joint that must be formed by dissimilar metals should be a metal lower in the electromotive force series than its mate (see Table 5-6). When two dissimilar metals must be bonded, metals that are close to one another in the electromotive force series should be selected.

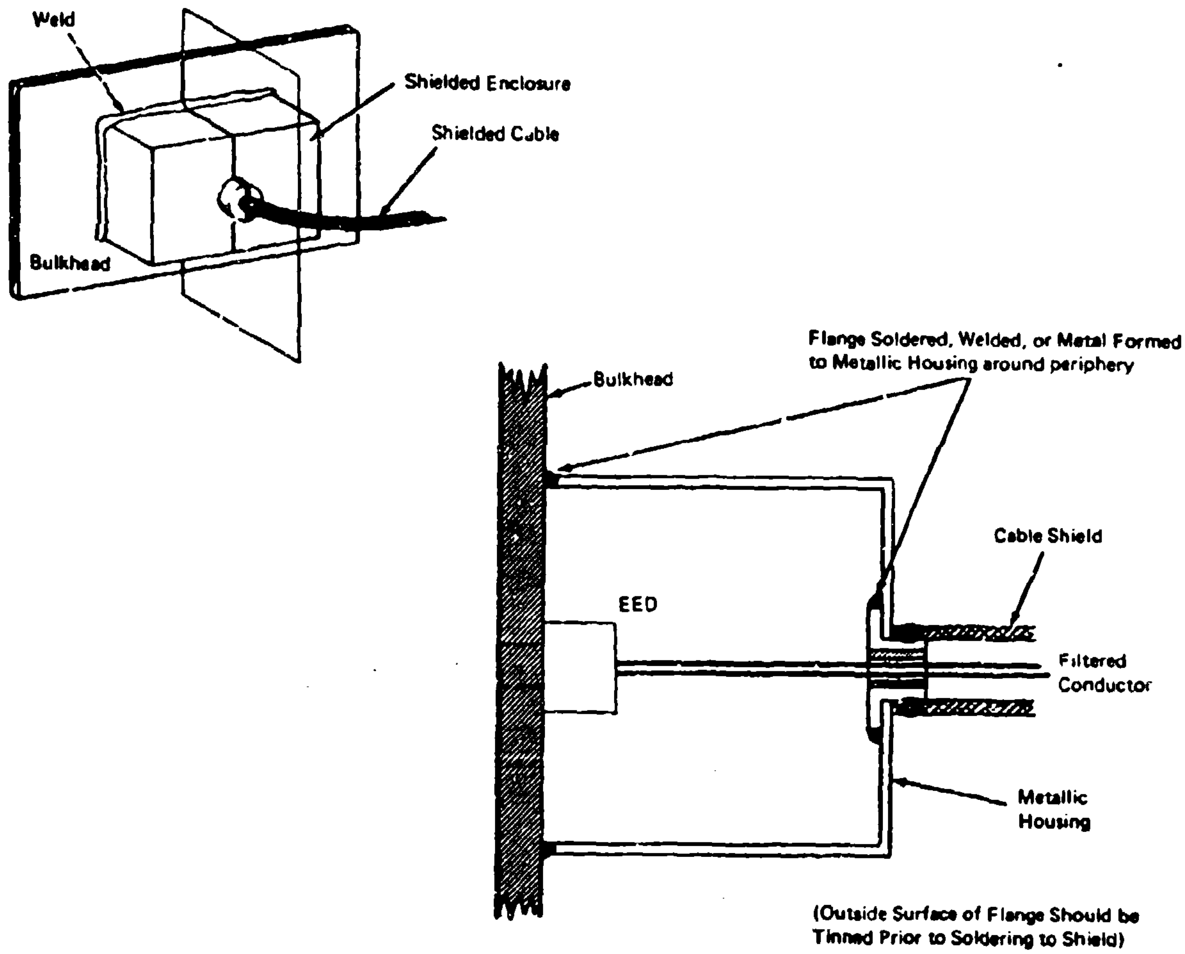


Figure 5-10. Acceptable Method of Routing Rigid Cable Through Shielded Enclosure

Bolted sections may be used for temporary bonds. However, bolted sections should be made as shown in Figure 5-13 to insure consistent contact pressure over an extended period of time. The shield material must be rigid enough to prevent buckling between contact points.

When bolts or rivets are used to make a bond, the bond should be made first at the middle of the seam and then toward the ends to prevent the mating surfaces from buckling. The shielding effectiveness of the joint is dependent upon the number of screws per linear inch and the pressure of the contacting surface.

When pressure bonds are made, the surfaces must be clean and dry before mating, and then held together under high pressure to minimize the chance of moisture forming in the joint. The periphery of the exposed joint should then be sealed with a suitable compound (and, whenever possible, one that is highly conductive to rf currents).

When protective coatings are required, they should be so selected that they can be easily removed from mating surfaces. Since the mating of bare metal to bare metal is essential for a satisfactory bond, a conflict may arise between the bonding and finish specifications. From the viewpoint of HERO, it is preferable to remove the finish where compromising of the bonding effectiveness would occur.

Certain protective metal platings such as cadmium, tin, or silver need not be removed. Most other coatings, however, are nonconductive and must be removed if a good bond is to be obtained.

When implementing bonding techniques, it must always be remembered that bonding straps do not provide a low impedance current path at rf frequencies. The impedance important in this discussion is the impedance at radio frequencies. There is little correlation between the dc resistance of a bond and its rf impedance. Even the measured

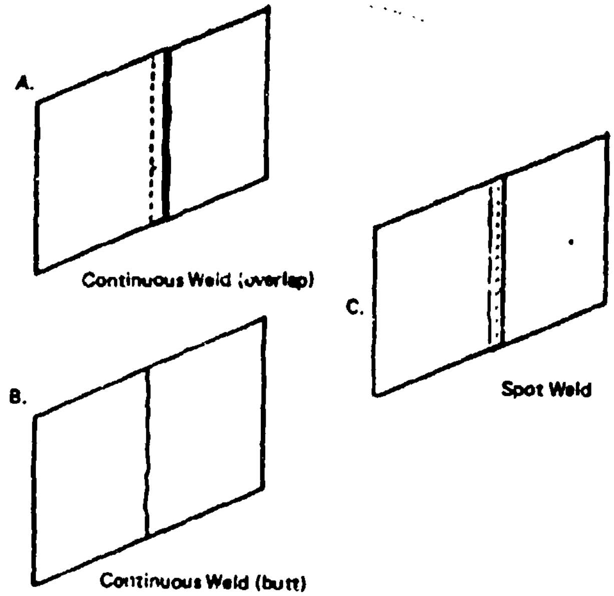


Figure 5-11. Panel Seam Configurations

Table 5-5. Types of Seams, In Order of Preference

Preference	Type Seam	Remarks
1	Continuous weld	Best rf seam
2	Spot weld	Space weld joints less than 2 inches apart
3	Crimp seam	Use strong and lasting crimping pressure

Table 5-6. Electromotive Force Series

(1)	Magnesium	(8)	Nickel
(2)	Beryllium	(9)	Tin
(3)	Aluminum	(10)	Lead
(4)	Zinc	(11)	Copper
(5)	Chromium	(12)	Silver
(6)	Iron	(13)	Platinum
(7)	Cadmium	(14)	Gold

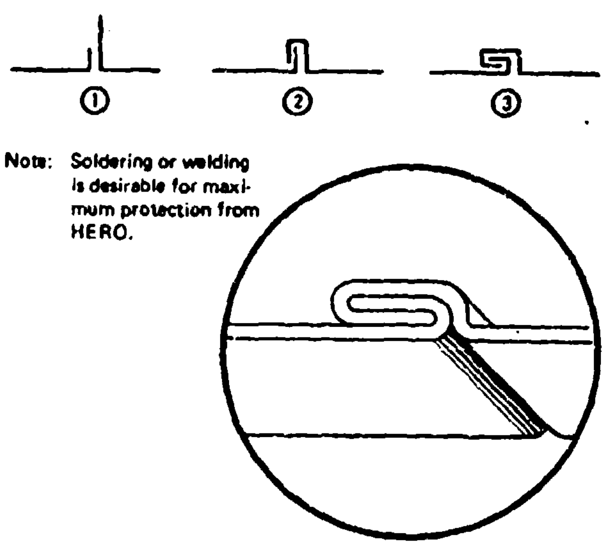


Figure 5-12. Formation of Permanent Crimp Seam

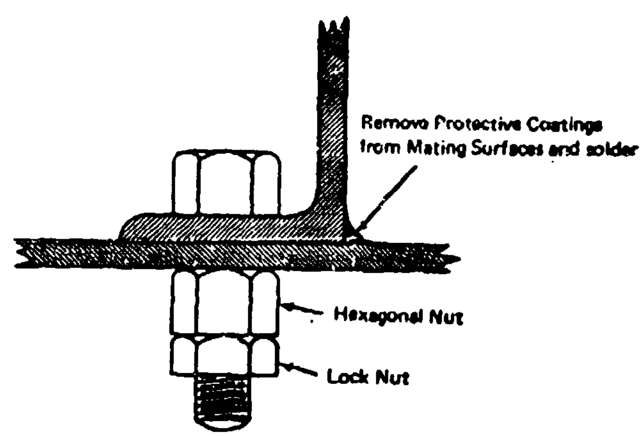


Figure 5-13. Acceptable Bonding Technique Using Bolts

rf impedance of bonds, such as jumpers, straps, rivets, etc., is not a reliable indication of the bonding effectiveness in the actual installation. It should also be remembered that conductive epoxies and pastes are not always sufficient rf bonds. Even when proven effective in given instances, they have been known to degrade shielding effectiveness under conditions of strain, pressure, and the passage of time.

5.10 GASKETS

Conductive gasket material can be used for bonding two surfaces when permanent bonding, such as continuous weld or crimp seams, cannot be used. The gasket material is inserted between the mating surfaces and a high pressure is maintained against the seam to insure good electrical bonding. It is essential to remove the protective coatings of

mating surfaces before the gasket material is inserted. They should also be free of oily film, corrosion, moisture, and paint.

Figure 5-14 illustrates an acceptable method of making a construction seam using rf gasket material. The features to be observed in the figure are:

1. Metallic surface machined to a smooth finish and all non-conductive materials removed.

2. Gasket bonded to one metallic surface of the seam. It is recommended that conductive adhesive be used for this application.

3. Appropriate material techniques (i.e., clamps, bolts, etc.) used to provide a high pressure on the rf gasket. The pressure must be nearly uniform along the entire length of the seam.

Figures 5-15 and 5-16 illustrate acceptable methods of making construction seams where sections must be removed and replaced for maintenance or loading and handling operations.

Table 5-7 is a guide to rf gasket design and usage.

Table 5-8 lists types of gaskets in order of preference.

Table 5-9 lists the three materials most frequently used for rf gaskets. They are ranked numerically for properties, with '1' indicating the most desirable material in a group and '3' the least desirable.

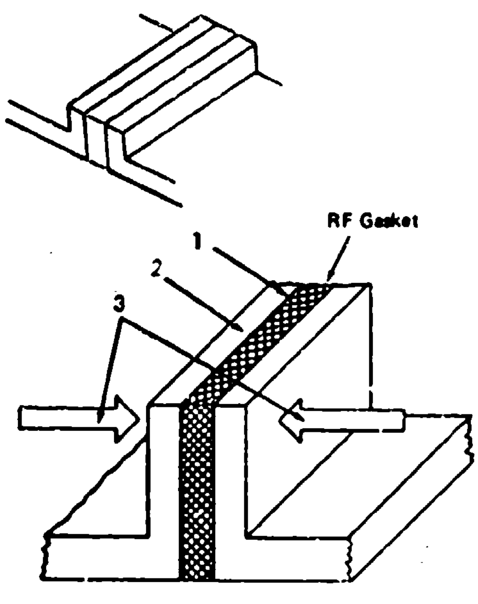


Figure 5-14. Acceptable Method of Making Permanent Seam Using RF Gasket

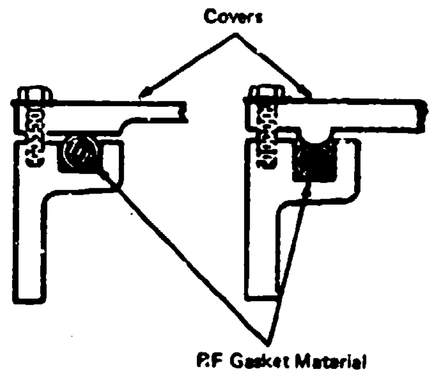


Figure 5-15. Cover Plates with Gaskets

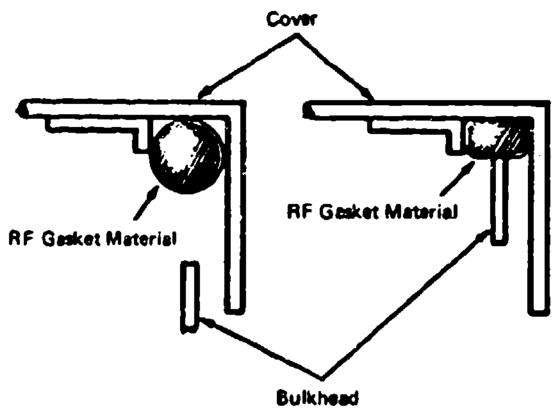


Figure 5-16. Covers with Gaskets

The first property considered is corrosion resistance. Both intrinsic corrosion resistance and resistance in presence of aluminum are given. The second comparison is given since rf gaskets are frequently used against aluminum structures and the question of compatibility arises.

The second property considered is conductivity. It should be noted that the intrinsic conductivity of the material is not the most important factor since corrosion films can form and these can greatly reduce the actual conductivity of an rf gasket. The material should be selected according to its conductivity with surface films. Both intrinsic conductivities and conductivities with surface film are given.

The mechanical properties of tensile strength, springiness, and hardness are marked as shown.

Table 5-7. RF Gasket Design and Usage

Gasket Consideration	Determined By
Material	Corrosion, mechanical wear, spring qualities, and rf properties
Form	Attachment methods, force available, other gasketing functions, joint unevenness, and space available
Thickness	Class of joint, joint unevenness, force available, and environmental level

Table 5-8. Types of Gaskets, in Order of Preference

Preference	Type Seam	Remarks
1	Metal mesh rf gasket	Subject to set; offers 54 dB attenuation at 20 psi; some evidence indicates attenuation highest at lower frequencies
2	Phosphor bronze spring fingers	Subject to breakage; offers approximately 60 dB attenuation
3	Conductive rubber	Satisfactory where nominal connection and small number of screws are required; some evidence indicates attenuation highest at higher frequencies

Table 5-9. Comparison of Three RF Gasket Materials

Material	Corrosion		Conductivity		Mechanical		
	Intrinsic	With Aluminum	Intrinsic	With Surface Film	Tensile	Spring	Hardness
Monel	1	2	3	1	1	2	1
Silver-plated brass	2	3	2	2	2	1	2
Aluminum	3	1	1	3	3	3	3

Aluminum comes out a poor third as a gasket material. Monel and silver plated brass rank close together. Considering all of these factors, it is recommended that monel be used for gasketing. There is one exception to this recommendation. Whenever specifications insist on the use of aluminum against aluminum, it is recommended that aluminum gasketing be used despite its poor properties.

5.11 TEMPORARY APERTURES AS DISCONTINUITIES

Temporary apertures of a weapon are those apertures, such as access panels, that must be open during adjustment or installation of circuits or components. They should be designed so that when they are closed, a low rf impedance electrical bond is maintained between the door or panel and the weapon housing. The best way of achieving this is to use metallic gaskets or finger stock between the mating surfaces. When metallic finger stock is used, 5 to 10 grams of pressure per finger should be applied to the mating surfaces.

If hinges are used on panels, it is recommended that gasketing such as conductive weather stripping be used on the hinged side of the panel. An alternative method for shielding at the hinge side of a panel is to use metal finger stock. The shielding material must be electrically and mechanically bonded to the frame at close intervals to insure proper shielding.

Figure 5-17 illustrates acceptable methods of applying shielding materials around the sides of hinged access panels. Appropriate mechanical locking devices must be used on access panels to

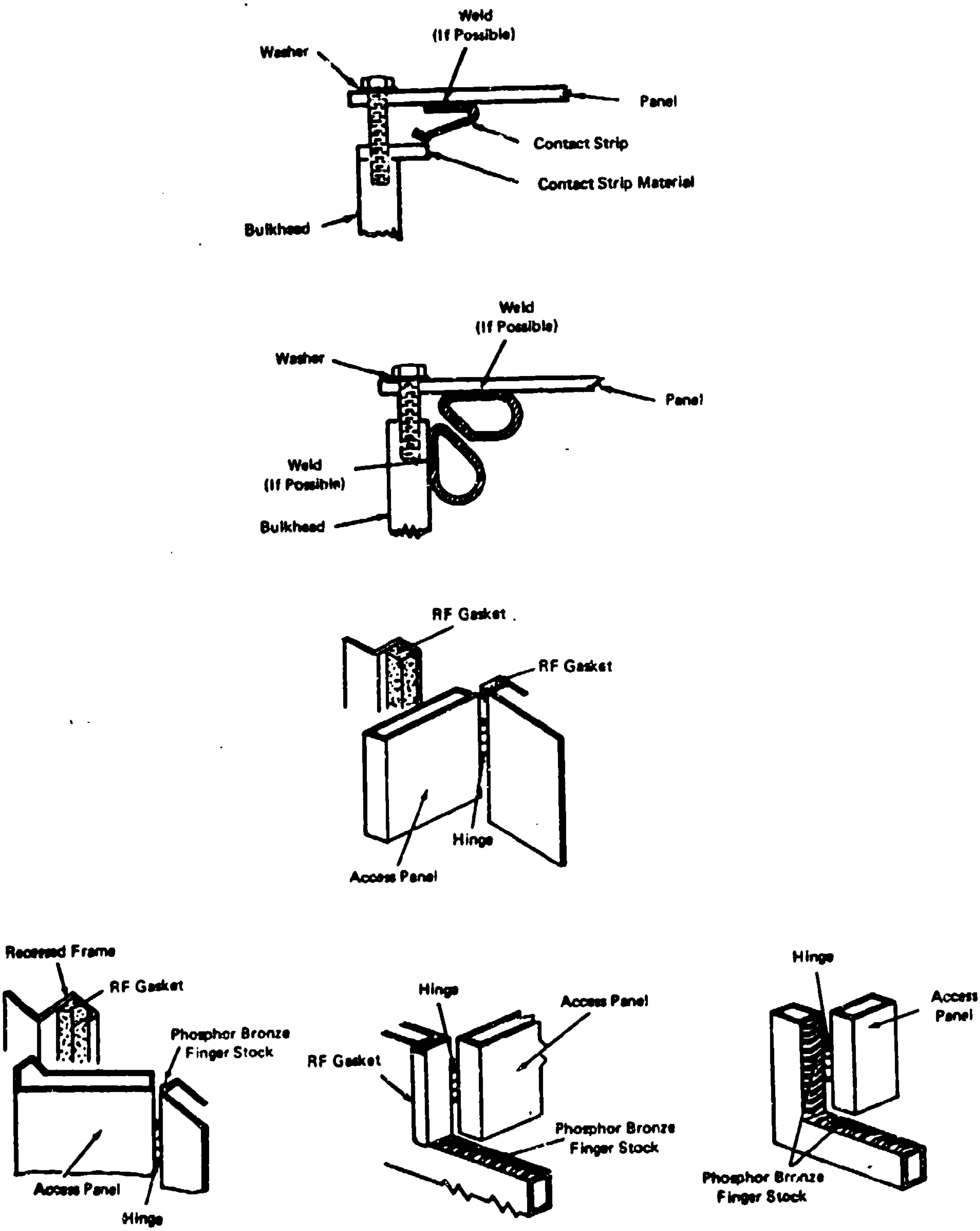


Figure 5-17. Acceptable Methods for Temporary Aperture Design

maintain a minimum of 20 psi pressure between the panel and the gasket or fingers.

The best arrangement of spring contact fingers around removable panels or doors calls for the installation of two sets of fingers at right angles to each other. One set is a wiping set, the other is in compression, and the combination makes good electrical contact when the door is closed. The pressure exerted by these springs is highly important and it should be carefully maintained.

Access panels or doors cannot perform a shielding function when opened or removed. If it is necessary for apertures to be opened in electromagnetic fields, the interior circuits, components, and cables should be designed to preclude HERO.

5.12 PERMANENT APERTURES AS DISCONTINUITIES

Permanent apertures are those holes or discontinuities in a weapon system housing which, for various reasons, cannot be shielded. Apertures for ventilation, control shafts, recessed firing pins, safe-and-arm device shafts, panel-mounted meters, exposed connector pins, and exhaust nozzles are common examples.

One method of minimizing the degradation of shielding effectiveness where small apertures are necessary is to design them so that they act as effective waveguide attenuators. Figure 5-18 illustrates how a necessary hole can be designed into a circular waveguide and used to pass a non-conducting shaft through the weapon housing.

An acceptable method of shielding apertures for meters or other panel-mounted readout devices is illustrated in Figure 5-19. Safe-and-arm

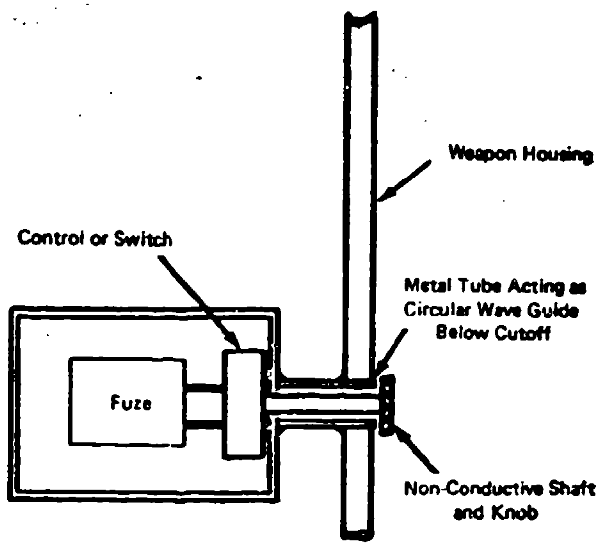


Figure 5-18. Acceptable Use of Circular Waveguide in a Permanent Aperture for Control Shaft

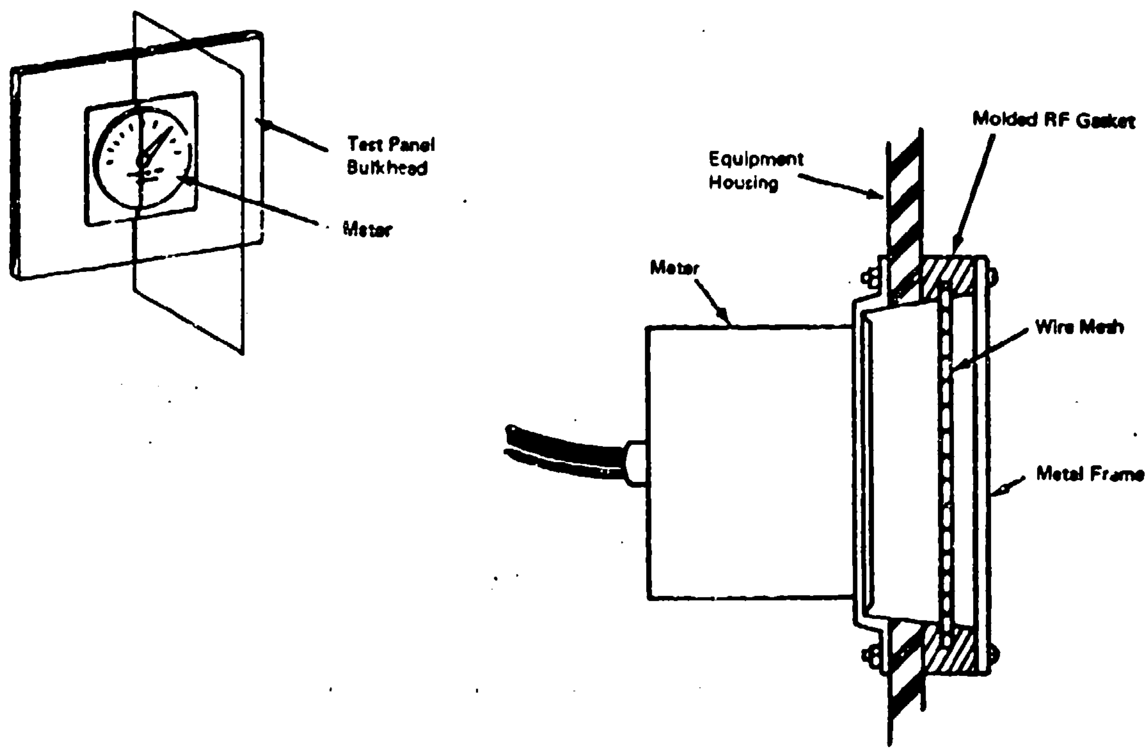


Figure 5-19. Acceptable Method of Shielding Panel-Mounted Meters

devices should be shielded as illustrated in Figure 5-20. Exhaust nozzles should also be shielded. A method that is convenient is to cover the nozzle with metal foil. An exhaust blast will simply tear the foil off the nozzle.

Where the use of waveguide materials is impractical or otherwise undesirable, as in the case of large ventilating holes, substantial attenuation of radiated electromagnetic energy can be obtained by covering the aperture with a wire screen or mesh. Number 22, 15-mil copper wire screen will provide more than 50 dB attenuation to electric and magnetic fields at frequencies between 1 MHz and 1 GHz. Figure 5-21 shows an acceptable technique for mounting a wire screen over an aperture. A similar mounting technique can be used in installing honeycomb material.

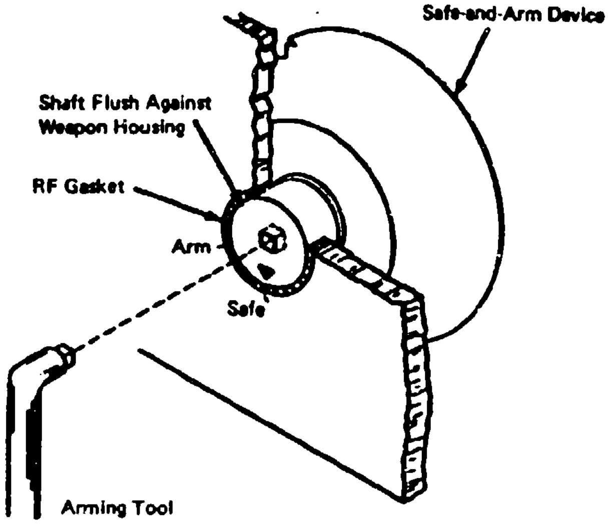


Figure 5-20. Acceptable Method of Shielding Safe and Arm Devices

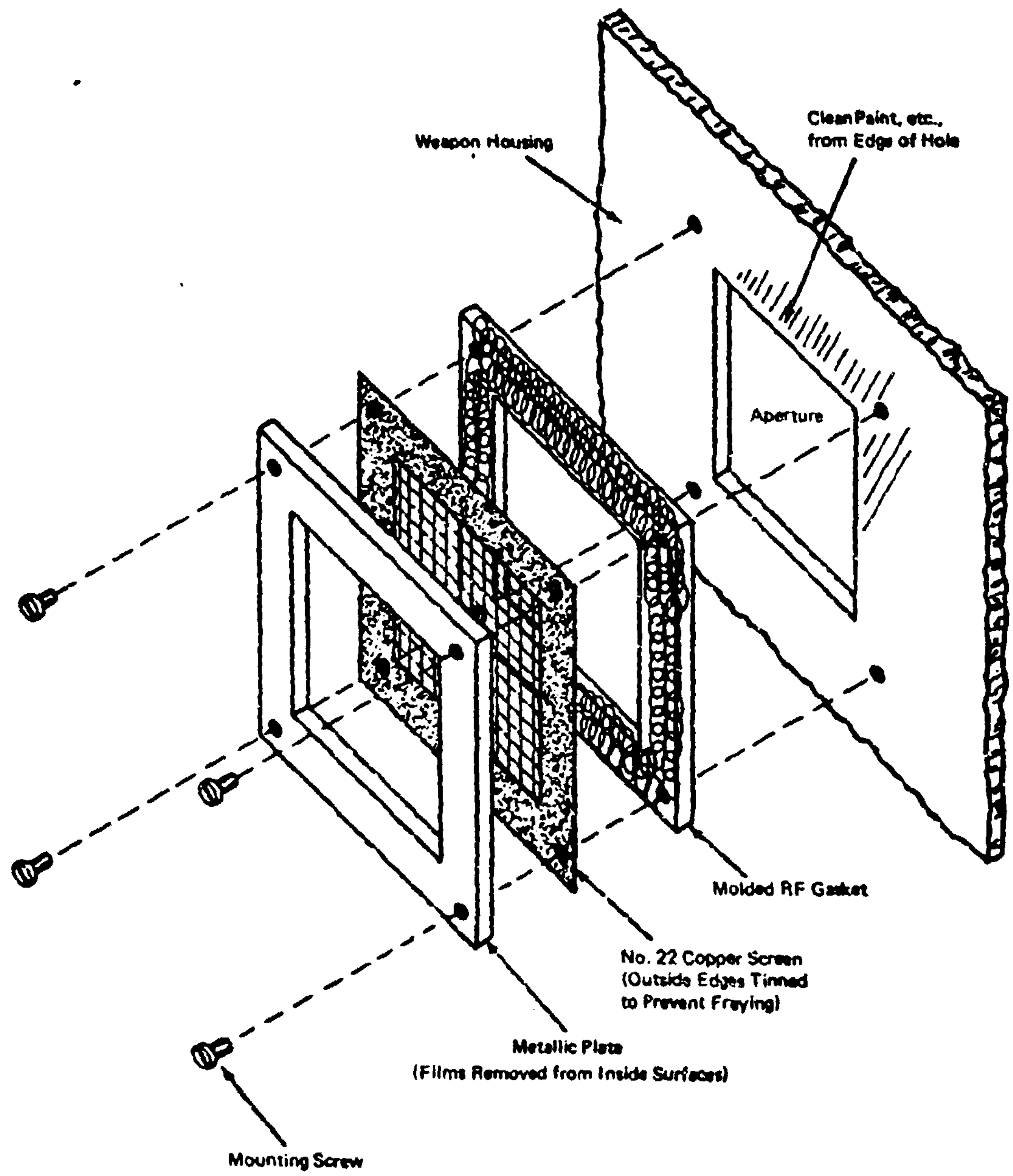


Figure 5-21. Method of Mounting Wire Mesh Over a Large Aperture

Chapter VI.
EMI SUPPRESSION DEVICES

6.0 GENERAL

Ordnance cannot always be protected from the electromagnetic environment by shielding and circuit design alone. Firing circuits and other circuits that penetrate the shield can conduct electromagnetic energy to the EED. To protect the weapon, these circuits must be filtered at their point of entry into the shielded enclosure. Low pass filters called EMI filters, have been developed for this application.

6.1 EMI FILTERS

EMI filters are filters that have broad band dissipative characteristics throughout the frequency range of interest. They are designed to operate with generator and load impedances that are outside those of a standard 50 ohm system. The generator, which is considered to be that system or circuit that delivers the energy to the EED or the filter, if a filter is used, includes the firing circuit wiring with its sources of induced energy plus any or all of the inductive, capacitive, and resistive elements that are electrically associated with it. Examples of these elements are personnel, equipment, aircraft, and the shipboard transmitting antenna systems. The impedance of this generator is the impedance seen by the filter, looking back into the firing circuit. It may be high or low; inductive, capacitive, or resistive; and it will vary with frequency throughout the entire spectrum. It is virtually undefined for existing weapons systems and will be entirely undefined for design-stage weapons.

The load for the filter is the EED and the portion of the firing circuit from the filter to the EED. The load impedance is the impedance of this system. It can take on any value and, also, can vary with frequency.

Since the generator and load impedances are unknown, insertion loss cannot be measured as specified in MIL-STD-220. MIL-STD-220 defines insertion loss in a 50Ω system (i.e., a 50Ω generator feeding a 50Ω load). This definition is not acceptable for HERO application. Insertion loss must be measured in accordance with MIL-STD-1377 (Navy) which is discussed in Chapter VII.

A filter can exhibit either or both of two types of loss when inserted into a system. These are: (1) a reflective loss due to mismatch of impedances between the filter and the source of energy, and (2) a dissipative loss that represents an actual loss of electrical energy in the form of heat. If the generator and load impedances were known, a reflective filter could be designed which would offer sufficient protection. But since these impedances are unknown, unpredictable, and constantly varying (as they are for HERO), a reflective filter cannot provide continuous, adequate protection across a wide range of frequencies. In fact, under varying generator and load impedances, a reflective filter may actually provide a conjugate impedance match between the electromagnetic energy source and the EED. Under maximum power transfer conditions, the filter, if depending on reflection losses alone, could actually increase the electromagnetic hazard instead of suppressing it as desired. Therefore reflective losses should be considered as a bonus rather than a design parameter. The dissipative loss provides protection that cannot be bypassed and the reflection loss reduces the thermal load of the filter.

To avoid impairing the effectiveness and reliability of the weapon, an EMI filter must have little or no attenuation to low frequency or dc energy (i.e., firing current). In addition, the filter together with the shielding available must provide the desired attenuation continuously across the frequency range of 20 KHz to 40 GHz.

Materials exist that have the unique characteristic of low dc attenuation and good high frequency attenuation over broad, continuous frequency ranges. Several dissipative materials--in particular, carbonyl iron mixes and ferrite compounds--are known as broad-band absorbers and are very useful in the design of EMI filters.

Another method of meeting the dissipative requirements for filter elements, is to utilize the "skin-effect." Skin-effect is the phenomenon that always occurs when electromagnetic energy is present in a conductor. The higher frequency energy is confined very near the skin or surface of the conductor, while low frequency (dc) energy is evenly distributed throughout the conductor. The higher the frequency the greater will be the confinement of the energy to the surface. Thus, as the frequency increases, the resistance increases. Various methods have been devised in an attempt to optimize this effect in designing EMI filters.

6.2 THE DESIGN OF EMI FILTERS

The design of filters for most applications has been covered in several design handbooks. However, the design of EMI filters represents a departure from these standard practices, not only because of the broad frequency spectrum covered but also because of the undefined input and output impedance. Instead of attempting to provide design information the preceding discussion has attempted only to outline the scope of the problem. It is recommended that EMI filters be obtained from sources that have developed or are capable of developing filters for this specialized purpose.

6.3 MOUNTING OF EMI FILTERS

The method used to mount an EMI filter must be such that it will leave the shielding of the enclosure intact. The overall effectiveness of even the most effective filter can be reduced to zero if it is improperly installed. Figure 6-1 illustrates both the acceptable and the unacceptable methods of mounting filters. The input and output of the filter must always be electrically isolated from one another. If the input to the filter is permitted to enter the shielded enclosure, the electromagnetic energy will enter the enclosure also, thus nullifying the effect of the filter.

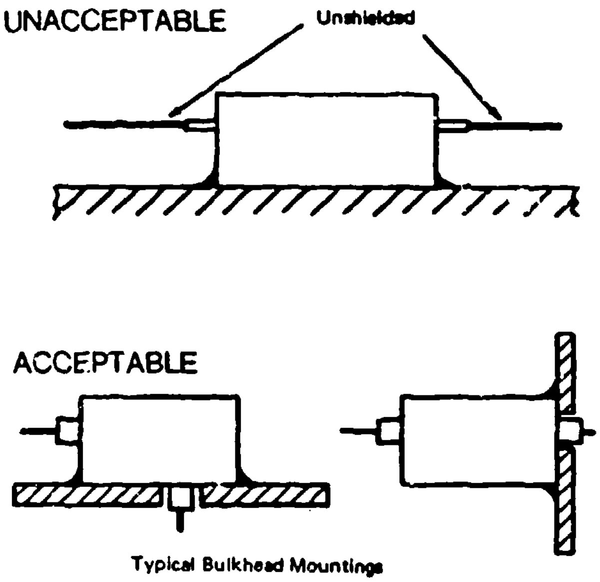


Figure 6-1. Methods of Mounting Filters

Figure 6-2 illustrates an acceptable method of mounting a filter when through the bulkhead mounting is not practical. In this situation, electromagnetic energy can be present in the enclosure where the EMI filter is mounted, but the shielded leads provide the shielding protection for the EED involved. The other EEDs in the enclosure must be filtered in a similar manner since the effectiveness of the shielding has been destroyed.

When used, dissipative filters must be mounted on a suitable heat sink. The heat sink must be capable of maintaining the temperature of the filter within the operating range of the material used in the filter.

6.4 ARC SUPPRESSION

Arc suppression methods are designed to prevent inadvertent initiation of an EED by the low frequency components of an arc. As previously discussed (Chapter I) the arc contains components at all frequencies. Since an EMI filter is designed to preclude only high frequencies from the electromagnetic environment and pass the low frequency firing

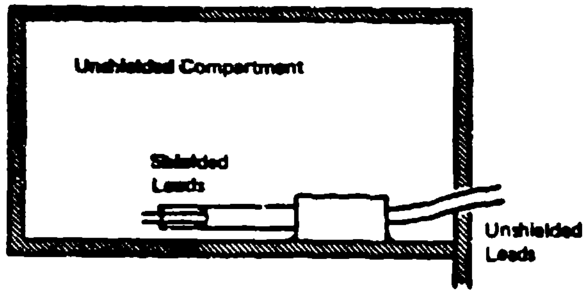


Figure 6-2. Acceptable Method of Mounting Filter when Bulkhead Mounting is Not Practical

signals, it is not capable of discriminating between the components of an arc and the intended firing signal. Therefore special techniques must be employed to provide protection against the HERO problem caused by arcing. In general, there are two methods that are used. These are: (1) provide open contacts in the firing system between the filter and the EED (see Figure 1-4, Chapter I), and (2) reduce the rf potential of the mating power contacts to zero prior to the final connection of the firing circuit to the weapon.

In the first method, the firing leads beyond the filter are broken by a switch such as a safe and arm switch until after all connections are made to the weapon. This is the best method since it eliminates the low frequency path to the EED while the switch is open. The low frequency energy of an arc that occurs at the connector will thus be prevented from passing to the EED. In this method the arrangement of components is usually connector, filter, safe and arm switch, and EED.

In the second method, the rf potential between the mating power contacts can be reduced by one or more techniques. One technique is to insure that no large rf potential exists between the weapon and the launcher when the final connections are made. At communication frequencies where arcs are a problem, approximately 200 to 300 volts is required to produce them. Such voltages can easily be obtained between an aircraft and the deck. If the weapon is not electrically connected to the aircraft, this voltage can exist between weapon and launcher. By insuring that the weapon makes contact with the launcher, the rf potential between them will be reduced so arcs will not occur when the final connection is made. Thus if the design and procedures are specified and arranged so that contact between the weapon and launcher is assured, this second method is feasible. Another technique is to use female connectors on the weapon side with recessed contacts to prevent touching them. The male connector should be of the type with 360° peripheral shielding and with power contacts that make and break only when the shield between the two parts of the connector is complete. If either or both of these techniques are followed, the designer will have reasonable assurance that arcing will not be a problem.

Chapter VII.
TESTING

7.0 GENERAL

NAVMAT Instruction 5101.1 requires that weapon systems and devices containing EEDs be reviewed and tested if deemed necessary and positive certification obtained that they can be handled with impunity in the maximum predicted electromagnetic environment before they are introduced into service use. For most systems this certification requires HERO evaluation tests.

7.1 PURPOSE

The purpose of this chapter is (1) to describe the nature and extent of the tests required for Navy certification, and (2) to introduce tests which may be conducted by the developer to assist him in implementing HERO design requirements.

7.2 NAVY HERO CERTIFICATION TESTS

The nature of weapon systems makes it mandatory for HERO testing to be conducted on an operational system with the entire weapon system exposed to the electromagnetic environment. In addition, the test conditions and procedures must be related to the shipboard electromagnetic environment (Chapter II). Navy HERO tests on both prototype and production models are normally conducted on a ground plane facility. In some instances weapon launcher size or unique ship interfaces dictate that the test be performed aboard ship.

7.3 GROUND PLANE AND LABORATORY TEST FACILITIES

In order to conduct HERO tests, ground plane facilities which permit convenient and adequate simulation of operating shipboard environments are required. These facilities include a ground plane of suitable size and location, together with appropriate radiation sources. HERO test facilities for Navy certification tests presently include three ground planes, shielded laboratory areas, and the equipment necessary for simulating the electromagnetic environment required to accomplish Navy HERO tests.

The ground planes measure 100 by 240 feet and are constructed of welded steel plates. Turntables are included to provide a convenient means of rotating the system under test so that a measure of the dependence of weapon susceptibility with respect to spatial orientation can be obtained. Figure 7-1 depicts one of the ground planes, its array of radiation sources, and a weapon system being tested.

Tests are conducted in the shielded areas of the laboratory in support of the ground plane test activities. These laboratory tests provide for component and subsystem tests, in addition to providing complete frequency coverage not possible on the ground plane.

7.4 PREPARATION OF THE WEAPON

To measure the amount of electromagnetic energy transferred from the environment to the EEDs in the weapon system, all explosives are removed from the weapon, and rf sensing devices are placed near the EED bridgewires. These sensors measure the absolute values of rf current induced at each EED location, thus yielding a quantitative measure of weapon susceptibility to electromagnetic energy.

7.5 ENVIRONMENT FOR TEST

The field levels in which the weapon will be tested are established prior to the tests. Typical communication and radar equipment is used to develop these field levels on the ground plane. Under all test conditions, either the field level is equivalent to the shipboard levels, or a known relationship exists which permits extrapolation of the test measurements to the shipboard electromagnetic environment.

7.6 TEST CONDITIONS AND PROCEDURES

The test conditions and procedures used to evaluate a weapon system are designed to simulate the physical and electrical environment that will be encountered in operational shipboard situations. The frequency and the radiated field levels used in the tests are established on the basis of experimental measurements taken aboard ship while the ship's communications and radar systems are operating.

The design of each weapon system includes specification of the loading and handling procedures to be used for that particular weapon system in all operations on board ship. These procedures consist of the use of carts and cranes, the loading and unloading operations, the handling and connecting of cables, the test and monitor functions on the aircraft and auxiliary equipment, the safe-and-arm functions, and any other operations leading to the launch of the weapon.

All of the procedures for a weapon system are incorporated as part of the HERO certification tests on that system. This policy insures that each weapon system is tested in an electromagnetic environment equivalent to that to which it will actually be subjected.

Some of the variables affecting the HERO characteristics of a weapon system, in addition to the

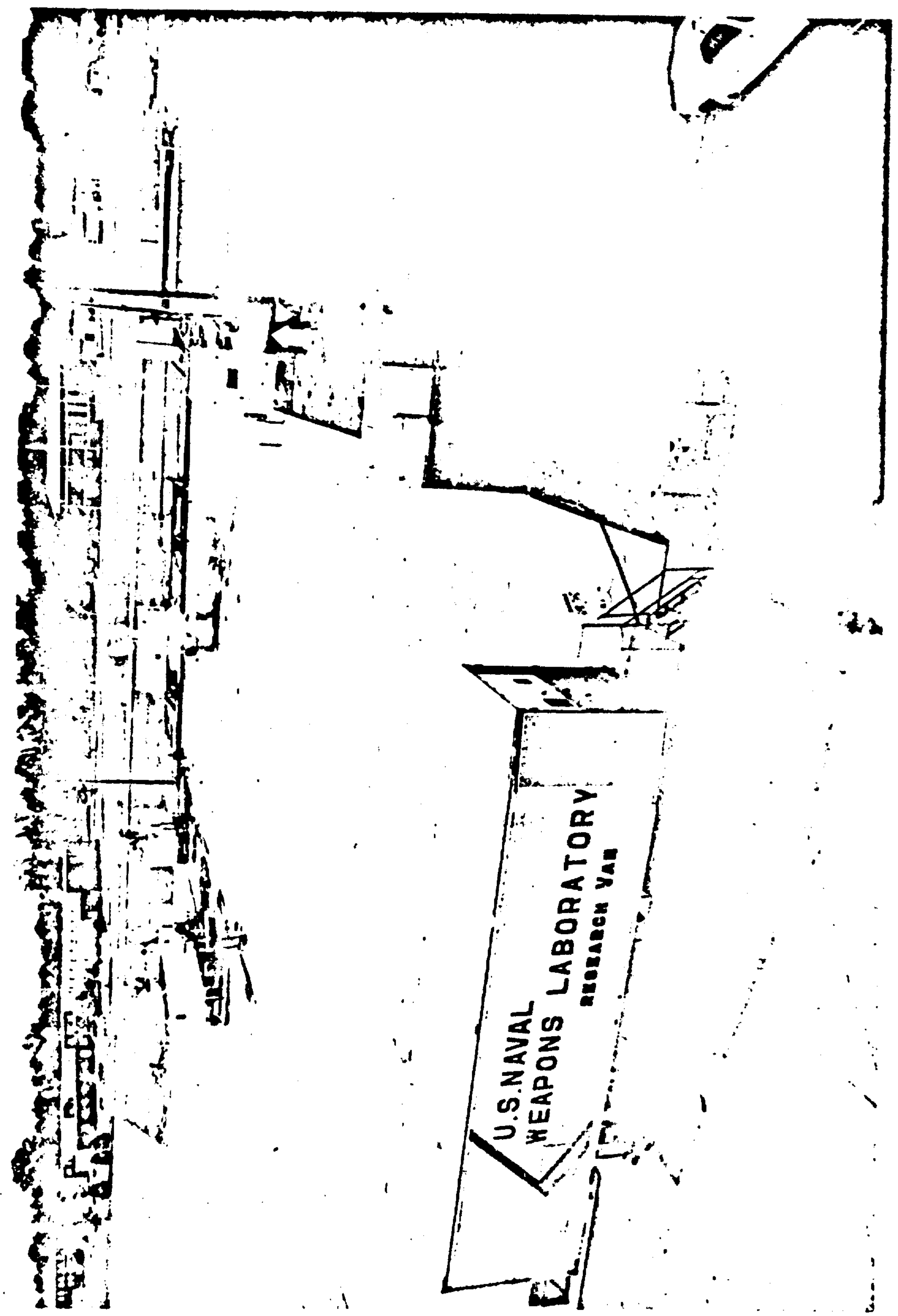


Figure 7-1. Ground Plane Test Facility, NWL, Dahlgren

handling and loading procedures previously mentioned, are frequency, field intensity, radiated power, weapon/aircraft orientation, and distance from the radiation source. Since there are many possible combinations of these variables, the tests are designed to examine those conditions most relevant to the hazard, while, if possible, exercising control over the less relevant factors. Examples of such factors are the proximity of personnel, adjacent structures, variations in grounding or tiedowns, and improper application of test and checkout equipment.

The results of the preceding tests are used to determine the level of susceptibility of the weapon in the expected shipboard electromagnetic environment. Additional tests are sometimes performed to determine the degree of susceptibility of the weapon system. These situations include unconventional handling procedures or environments of higher electromagnetic energy levels. Observation of weapon system susceptibility under such conditions leads to procedures that assure the safety and reliability of the weapon system throughout the stockpile-to-launch sequence.

7.7 PROTOTYPE VERSUS PRODUCTION WEAPONS TESTS

The test and evaluation of the HERO susceptibility of weapon systems must not be considered an "after-the-fact" responsibility. A continuous assessment of HERO susceptibility throughout the design-prototype-production phases of development must be implemented.

When the prototype systems have successfully passed the HERO test, any change, however insignificant, must be recognized as a potential problem area. If it is impossible (or undesirable in a performance sense) to maintain continuity from prototype to production models, the modification in design must be such that the weapon remains as safe as the tested prototype from the standpoint of HERO problems. Many of these changes will require additional HERO tests. It is assumed that when the weapon system has reached the production phase, the design of all components and subsystems should have progressed to a stage where a series of routine tests and evaluations will be sufficient to verify that the weapon complies with requirements for precluding HERO problems and can be certified for unrestricted use in the fleet.

7.8 HERO TESTS FOR WEAPONS DESIGNERS

MIL-STD-1385(Navy) establishes the general requirements and acceptance criteria for precluding electromagnetic energy from electrically sensitive weapon system components. Methods of implementing these requirements have been established and are presented in previous chapters.

The system evaluation tests performed to final acceptance of the weapon system by the Navy (see Section 7.2) cannot be conducted until all components have been fabricated and the complete weapon assembled. By the time this phase has been reached, the design is firm, and in many cases, production of the weapon has started. If the weapon fails to meet the HERO evaluation criteria, costly retrofits and redesign may be required.

Previous Navy evaluation tests have demonstrated that little consideration was given to the HERO problem during the design stages of weapons presently in use in the fleet. Visual inspection of these systems would have been sufficient to detect such obvious deficiencies as long unshielded umbilical cables and wires, plastic sections, and access doors that must be opened in the electromagnetic environment. There are, however, some serious design deficiencies that will not always be apparent from visual inspection. Among the most important of these are inadequate shielding and filtering.

To detect such deficiencies, to optimize design, and to implement quality control, it is imperative to apply qualitiative testing techniques during the developmental stages of the system. As a result of an extensive research program a series of such testing techniques have been developed and presented in Military Standard MIL-STD-1377(Navy). These test methods include techniques for evaluating shielding effectiveness of weapon enclosures and connectors and for measuring filter effectiveness.

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